

Exploring the Viability of Solar Photovoltaic for Rural Water Supply in Ghana: A Case Study of Agotime-Ziope District of the Volta Region

By

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DECLARATION

I hereby declare that this submission is my own work towards the PhD and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

ABSTRACT

Availability of good drinking water is a key factor for health and quality of life. In urban locations of Ghana, water from large rivers is abstracted and treated before it is supplied to the urban people by the use of the grid. However access to potable water is difficult in rural communities of the country because these locations are remote from the grid (or they experience unreliable power supply) and water infrastructure. They are however endowed with abundant sunshine (5-8 hours per day with irradiation ranging 3.1-6.5 kW/m²-day), small rivers and streams. In spite of these natural resources, the potable water (from local treatment plants and groundwater sources) coverage in most of these locations is as low as 21%. During the dry season, the water levels reduce and some dry up completely making water and sanitation major development concerns for communities in these locations. This research therefore sought to explore the viability of solar PV water pumping in rural locations of Ghana, using the Agotime-Ziope district as case study. The case-based action research addressed the factors that influence the take up of solar energy for water pumping in rural locations of the country. Both quantitative and qualitative studies were conducted. Quantitative results derived from a questionnaire and qualitative obtained from the interviews conducted with the district officials, stakeholders in the solar industry and villagers in seven specific communities, are presented. The quantitative and qualitative approaches were mixed in the study. Furthermore, a solar PV pumping system for Kporta community was designed, installed and the system's performance was evaluated in relation to how the people in the community collected water from it. The new PV system supplies adequate water to the people as it was designed, thus demonstrating the viability of solar PV for water supply. This notwithstanding, the system was underutilized by the community; since out of the 1,825,000 litres of water it was designed to supply in one year, only 5.2 % of water was collected from the system in one year. Two reasons are suggested for the low patronage: firstly, the borehole water at Kporta had a high content of magnesium, sulphate and chloride above WHO's standard values making the water hard and taste salty. Secondly, water is available (free of charge) from the community pond (dam) which is perceived to be better (water is soft and does not taste salty even though unhygienic). On the other hand, in Lume Avete where a PV system supplies high quality safe drinking water (water is soft and does not taste salty) from underground, the community makes maximum use of the system. High upfront PV system cost and lack of awareness of the technology also influence its adoption and wider diffusion. Two frameworks were developed within the thesis; one for the PV system market structure

and the other for its financing to address the cost and awareness factors. Within the financing framework are five models namely; 100 % upfront cash payment, fee-for-service, build operate and transfer, donation and PV utilization loan. It is recommended that future research should develop methods to remove salt and dissolved minerals from groundwater in the district and develop a better understanding of how best to supply safe water in rural areas of the country.

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DEDICATION

I dedicate this work to my dear wife Ruth and our children: Martin Kwasi; Ethel Esinu and Theodora Kekeli Dzokoto and Archibald Kpodo for their prayers and moral support they gave me during my course of study. May God bless you.

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ACRONYMS

ACT 564	Act established Community Water and Sanitation Agency in 1998
ACT 832	Act established Renewable Energy Technology in December 2011
AfDB	African Development Bank
AGSI	Association of Ghana Solar Industries
AMCOW	Africa Ministers' Council on Water
AT	Appropriate Technology
AVRL	Aqua Vitens Rand Limited
BECE	Basic Education Certificate Examination
BH	Borehole
BOT	Build Operate Transfer
CA	Community Agent
CEOs	Chief Executive Officers
CIDA	Canadian International Development Agency
COM	Community Ownership and Management
COCOBOD	Ghana Cocoa Marketing Board
CONIWAS	Coalition of NGOs in Water and Sanitation
CSO	Civil Society Organization
CWSA	Community Water and Sanitation Agency
CWSD	Community Water and Sanitation Division
DA	District Assembly
DANIDA	Danish International Development Agency
DCD	District Coordinating Director
DCE	District Chief Executive
DDPO	District Development Planning Officer
DfID (UK)	Department for International Development
DPs	Development Partners
DSTC	Deng Solar Training Centre
DWST	District Water and Sanitation Team
ECG	Electricity Company of Ghana
ECOWAS	Economic Community of West African States
EHSD	Environmental Health and Sanitation Directorate
EPA	Environmental Protection Agency
EPIA	European Photovoltaic Industry Association

ESA	External Support Agency
EU	European Union
FfS	Fee-for-service
FiT	Feed-in Tariff
GDP	Gross Domestic Product
GEDAP	Ghana Energy Access and Development Project
GH¢	Ghana Cedi
GHGs	Green House Gases
GoG	Government of Ghana
GRIDCo	Ghana Grid Company
GSA	Ghana Standard Authority
GSB	Ghana Standard Board
GSESPL	Global Sustainable Energy Solutions
GSS	Ghana Statistical Service
GTZ	German Technical Cooperation
GW	gigawatt
GWCL	Ghana Water Company Limited
GWh	gigawatt-hours
GWSC	Ghana Water and Sewerage Corporation
HDI	Human Development Index
HOMER	Hybrid Optimisation Model Electric Renewable
HSD	Hydrological Services Department
IEA	International Energy Agency
IPP	independent power producer
IRENA	International Renewable Energy Agency
ISODEC	Integrated Social Development Centre
JHS	Junior High School
JICA	Japan International Cooperation Agency
JMP WHO/UNICEF	Joint Monitoring Programme
km	kilometre
KNUST	Kwame Nkrumah University of Science and Technology
kV	kilovolt
kW	kilowatt per square metre
kW/m ² /day	kilowatt per square metre per day

kWh	kilowatt-hour
kW _p	kilowatt-peak
LCC	life-cycle cost
LI	Legislative Instrument
LPG	Liquefied Petroleum Gas
M&E	Monitoring and Evaluation
m/s	metres per second
m ³	cubic metres
MDG	Millennium Development Goal
MLGRD	Ministry of Local Government and Rural Development
MMDA	Metropolitan/Municipal/District Assembly
MoEP	Ministry of Energy and Petroleum
MoP	Ministry of Power
MOU	Memorandum of Understanding
MW	megawatts
MWRWH	Ministry of Water Resources, Works and Housing
NCWSP	National Community Water and Sanitation Programme
NEDCo	Northern Electricity Distribution Company
NEP	National Electrification Programme
NEPAD	New Partnership for Africa's Development
NES	National Electrification Scheme
NGO	Non-Governmental Organization
NGOs	Non-governmental organisations
OECD	Organization for Economic Co-operation & Development
PAYF	Pay As You Fetch
PO	Private Operator
PSH	Peak Sun Hour
PURC	Public Utility Regulatory Commission
PV	Photovoltaic
PVA	Photovoltaic Agent
PVUL	Photovoltaic Utilisation Loan
RE	Renewable Energy
RESPRO	Renewable Energy Service Project
RET	Renewable Energy Technology

RWSP	Rural Water and Sanitation Project
RWST	Regional Water and Sanitation Team
SE4All	Solar Energy for All
SENG	Sustainable Energy Network of Ghana
SHEP	Self Help Electrification Project
Shs	solar home system
SHS	Senior High School
SIP	Sector Investment Plan
SNEP	Strategic National Energy Plan
SOE	State Owned Enterprise
SPSS	Statistical Package for Social Scientists
SSA	South Saharan Africa
SSC	Solar Service Centre
STR	Stream
TDH	Total Dynamic Head
UN	United Nations
UNICEF	United Nations Children's Education Fund
USD	United States Dollar
VAT	Value Added Tax
VRA	Volta River Authority
WAGP	West Africa Gas Pipeline
WASH	Water, Sanitation and Hygiene
WATSAN	Water and Sanitation
WHO	World Health Organization
WRC	Water Resources Commission
WSDBs	Water and Sanitation Development Boards
WSMP	Water and Sanitation Monitoring Platform
WSMT	Water and Sanitation Management Team
WSP	Water and Sanitation Program

CHAPTER ONE: INTRODUCTION

“We must not fail the billions who look to the international community to fulfill the promise of the Millennium Declaration for a better world. Let us keep the promise” – UN Secretary -General Ban Ki-moon (United Nation, 2010).

1.1 Overview of Energy and Water Access

Access to sustainable energy services and safe drinking water is crucial to meeting the developmental needs of more than 1.2 billion people around the globe who are living under abject poverty conditions (Chaurey and Kandpal, 2010). Water and sunlight have been identified as the most vital natural resources for all life on the earth and for man’s survival (Omer, 2001).

Availability of hygienic drinking water is a key factor for health and quality of life. Energy for pumping usually dominates discussions which are held on supply of safe drinking water. Thus in this study, energy and water supply in the rural locations of Ghana have been discussed using Agotime-Ziope district as a case study. The research sought to explore the viability of solar PV in water supply for rural locations of Ghana. The next section is a brief world overview on water.

1.1.1 World Overview on Water

Water had received international recognition decades ago. This recognition had been demonstrated in the international front at different global fora which have been extended to regional and national levels. Notable among them are: the UN’s Earth Summit held in 1992, the 1992 Dublin Conference, the Water Supply and Sanitation Collaborative Council’s Global Water forums, and the World Water Council’s World Water forums (WHO, 2004; Entsua-Mensah et al, 2007; Gbedemah, 2010).

From Solanes et al., (1999), the Dublin Conference at which the Dublin Principles were developed for instance states:

- i. Fresh water is a finite and vulnerable resource, essential to sustain life, development and the environment.
- ii. Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels.
- iii. Women play a central part in the provision, management and safeguarding of water.

- iv. Water has an economic value in all its competing uses and it should be recognized as economic good.

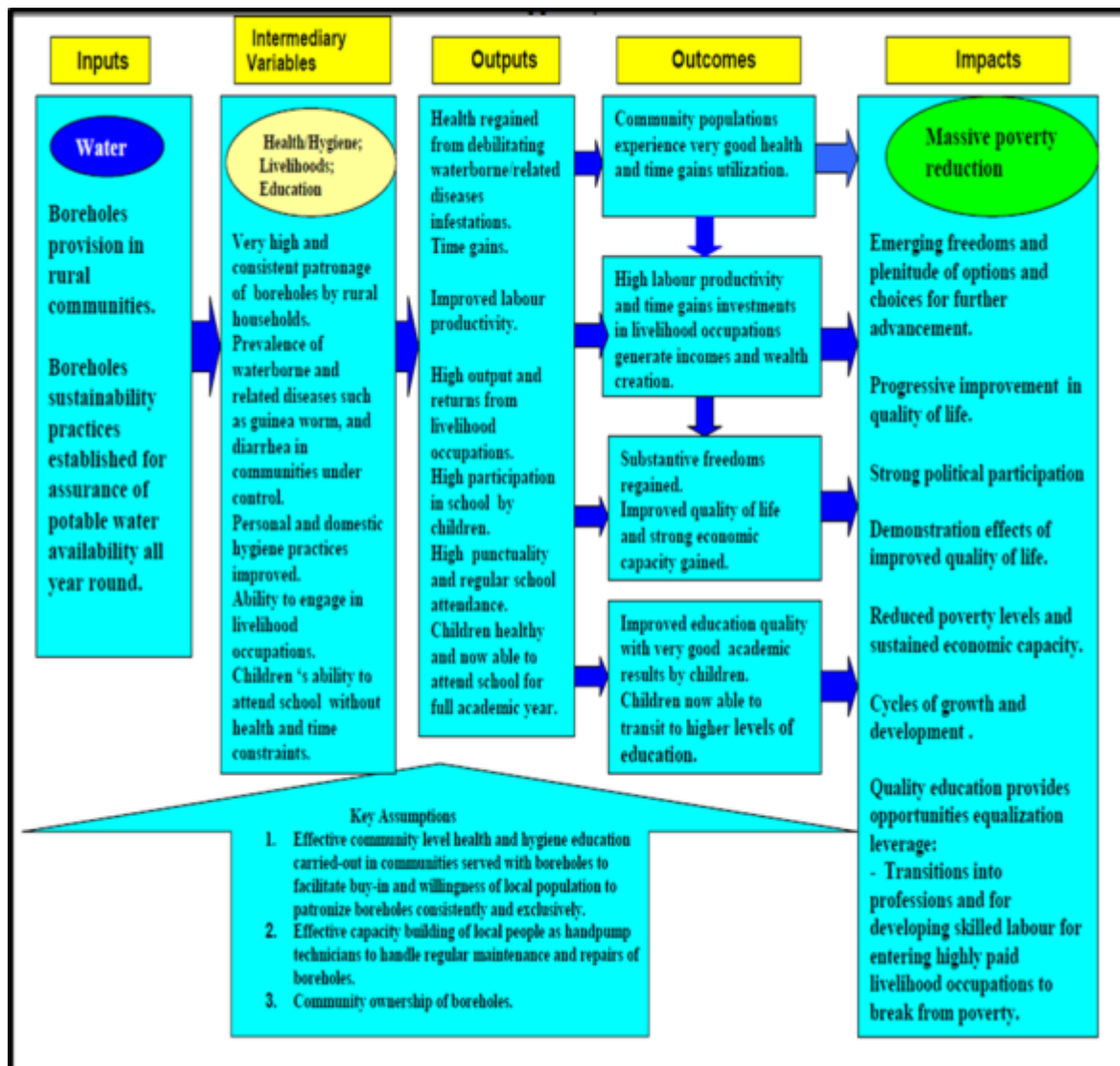


Figure 1.1: Adow's conceptual framework for rural poverty reduction based on borehole provision Adow (2013)

Adequate supplies of clean water and energy is said to be the basis for higher standards of living, improved quality and quantity of human capital (Kaygusuz, 2012; Adow, 2013). Giving illustration in terms of provision of clean water using borehole (as opposed to water from unimproved sources) for example, Adow (2013) presented a model shown in figure 1.1 linking borehole provision to health, hygiene, livelihood, incomes and education in facilitating poverty reduction in rural communities the world over. According to him, supply of boreholes in rural communities creates access to hygienic water sources and contributes to

the eradication of water-borne and water-related diseases such as diarrhoea and guinea worm (Adow, 2013).

In the next section, an overview on energy from international through regional to national levels is considered.

1.1.2 World Overview on Energy

Even though energy is not mentioned explicitly in the eight Millennium Development Goals (MDGs) listed below, many researchers argue that the goals have a strong link with energy (GNESD, 2007; Kankan et al., 2009; Chaurey and Kandpal, 2010; Brew-Hammond, 2010; Kemausour et al., 2014) since access to clean, affordable and suitable energy services would be a critical factor in achieving almost all the MDGs (GNESD, 2007; Chaurey and Kandpal, 2010; Atsu et al., 2016) and for sustainable development. This clearly implies that the sustainable development of communities hinges on energy. According to Nelson (2007), Easterly (2009) and Sahn and Stifel, (2003), the MDGs are:

- Goal 1 Eradicate extreme poverty and hunger
- Goal 2 Achieve universal primary education
- Goal 3 Promote gender equality and empower women
- Goal 4 Reduce child mortality
- Goal 5 Improve maternal health
- Goal 6 Combat HIV/AIDS, malaria and other diseases
- Goal 7 Ensure environmental sustainability
- Goal 8 Develop a global partnership for development

Giving illustration of the links between energy and human, economic and social development in figure 1.2, Kaygusuz (2012) points out that energy supply is the basis for enhancing the business and natural environment, and increasing the efficiency of government policies.

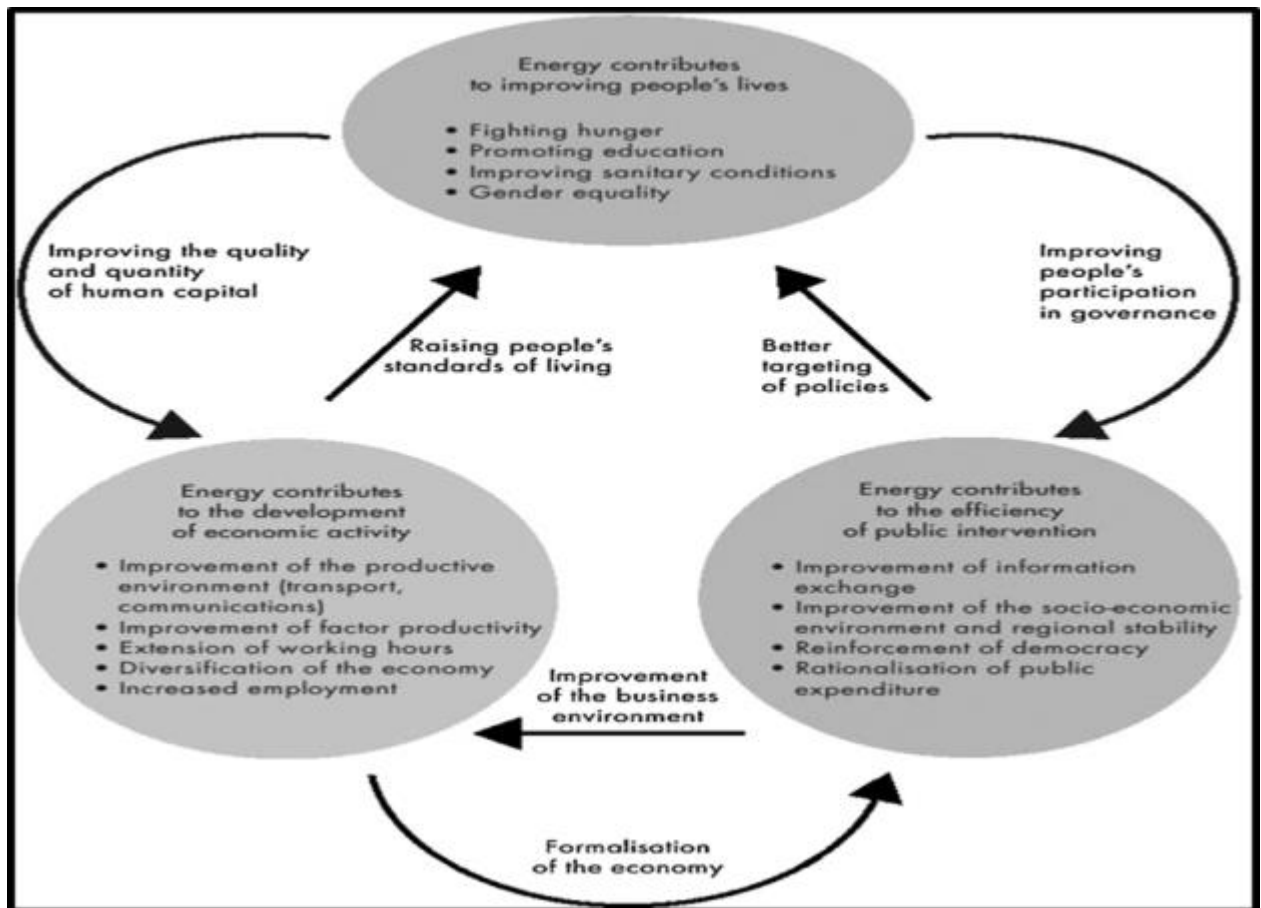


Figure 1.2: Links between energy and human, economic and development *Kaygusuz (2012)*

In the following section, the level of electrification access within regions all over the world is considered and depicted in table 1.1. While many researchers acknowledge the fact that energy access is the way to go in tackling poverty challenges and issues of sustainable development, access to clean energy the world over is still difficult.

Table 1: Level of electrification in various regions in 2009

Region	Population without electricity (Millions)	Electrification rate (%)		
		Overall	Urban	Rural
North Africa	2	99.0	99.6	98.4
Sub-Saharan Africa	585	30.5	59.9	14.2
Africa	587	41.4	66.8	25.0
China and East Asia	182	90.8	96.4	86.4
South Asia	493	68.5	89.5	59.9
Developing Asia	675	81.0	94.0	73.2
Middle East	21	89.0	98.5	73.6
Latin America	31	93.2	98.8	73.6
Developing Countries	1,314	74.7	90.6	63.2
Global Total	1,317	80.5	93.7	68.0

IEA (2011); Bhattacharyya, 2013

The global electrification access problem has distinct regional dimensions (IEA, 2011; Kaygusuz, 2012; Bhattacharyya, 2013). Table 1.1 illustrates the level of electrification in various regions across the world as of 2009. In the table, it can be seen that Developing Asia and Sub-Saharan Africa are two regions where the problem is severe. In Developing Asia for instance, 675 million people lack access to electricity while 585 million people in Sub-Saharan Africa face the same setback (Bhattacharyya, 2013). The rural population in most of these countries lack access to electricity as do some of the urban populations. McNeli (2004) when comparing electricity access in 2002 with what the situation might be in 2030 predicts that even if 2 billion people gain access, because of population increase there will still be 1.4 billion people without electricity by 2030 (McNeli, 2004). This prediction is not too different from figures reported by other researchers. For instance, 1.4 billion people are estimated to have lacked access to electricity; in another case, 2.7 billion people are estimated to rely on the conventional use of biomass for cooking (IEA, 2010; Kaygasuz, 2012). The lack of access to electricity, and hence the excessive use of fossil fuel and biomass will have adverse effect on human health, economic development and environmental sustainability in many parts of the world.

In order to reverse the trend, Kaygusuz (2012) suggests that governments of developing countries, together with investors and donors, must find more efficient and less costly ways of delivering energy services which may also help to meet other sustainable development needs (Kaygusuz, 2012). One such efficient way suggested by researchers is the use of renewable energy (Razykov et al., 2011; Sopian et al., 2011). Bhattacharyya (2013) argues that the emergence of renewable energy technologies, poor and erratic supply from the central grid at locations where the grid could be found, and the support for-low carbon energy solutions in response to climate change concerns have given further support to the alternative energy option. According to him decentralized solutions which are technically possible have been promoted at off grid locations or where the grid is not likely to reach in the near future (Bhattacharyya, 2013). This is laudable because it is those remote locations that lack access to electricity most.

Having considered the international energy situation, the next section briefly deals with energy issues in the sub-Saharan Africa and national energy situations.

In the African region for instance, the New Partnership for Africa's Development (NEPAD) is reported to have put forward a strategic development vision with clear objectives for meeting the energy needs of the region (NEPAD, 2001; Brew-Hammond, 2010). NEPAD set the following objectives:

- i. To increase from 10 % to 35 % or more, access to reliable and affordable commercial energy supply by Africa's population in 20 year;
- ii. To improve the reliability as well as lower the cost of energy supply to productive activities in order to enable economic growth of 6 % per annum;
- iii. To reverse environmental degradation that is associated with the use of traditional fuels in rural areas;
- iv. To exploit and develop the hydropower potential of river basins of Africa;
- v. To integrate transmission grids and gas pipeline to facilitate cross-border energy flows;
- vi. To reform and harmonise petroleum regulations and legislation in the continent.

Following the lead taken by NEPAD, sub-regional economic communities have also put forward their own strategic energy plans towards achieving the MDGs and realizing the NEPAD objectives (Brew-Hammond, 2010). At a national level, governments have also

initiated their strategic energy plans and schemes for addressing their energy problems. The following section discusses the background of Ghana. It presents the country's map showing the ten administrative divisions (regions).

1.2 Brief Background of Ghana

This section gives a brief background of Ghana, specifically touching on its location and climate, socio-economic and political life. Energy trend and water supply in rural locations of the country have been discussed in chapter 2 of the thesis and hence are not considered in this section.

Ghana is situated in the centre of the West African coast and shares borders with three French-speaking nations, namely: Burkina Faso to the North, la Cote d'Ivoire to the West and Togo to the East. The Southern parts are bounded by the Gulf of Guinea which is part of the Atlantic Ocean. Figure 1.3 is the map of Ghana showing the 10 administrative divisions (called regions) and the neighbouring countries. The country has a total land area of 238,533 square kilometres. It lies on latitude $5^{\circ} 36'$ north of the equator and longitude $0^{\circ} 10$ minutes east (Energy Commission, 2009).

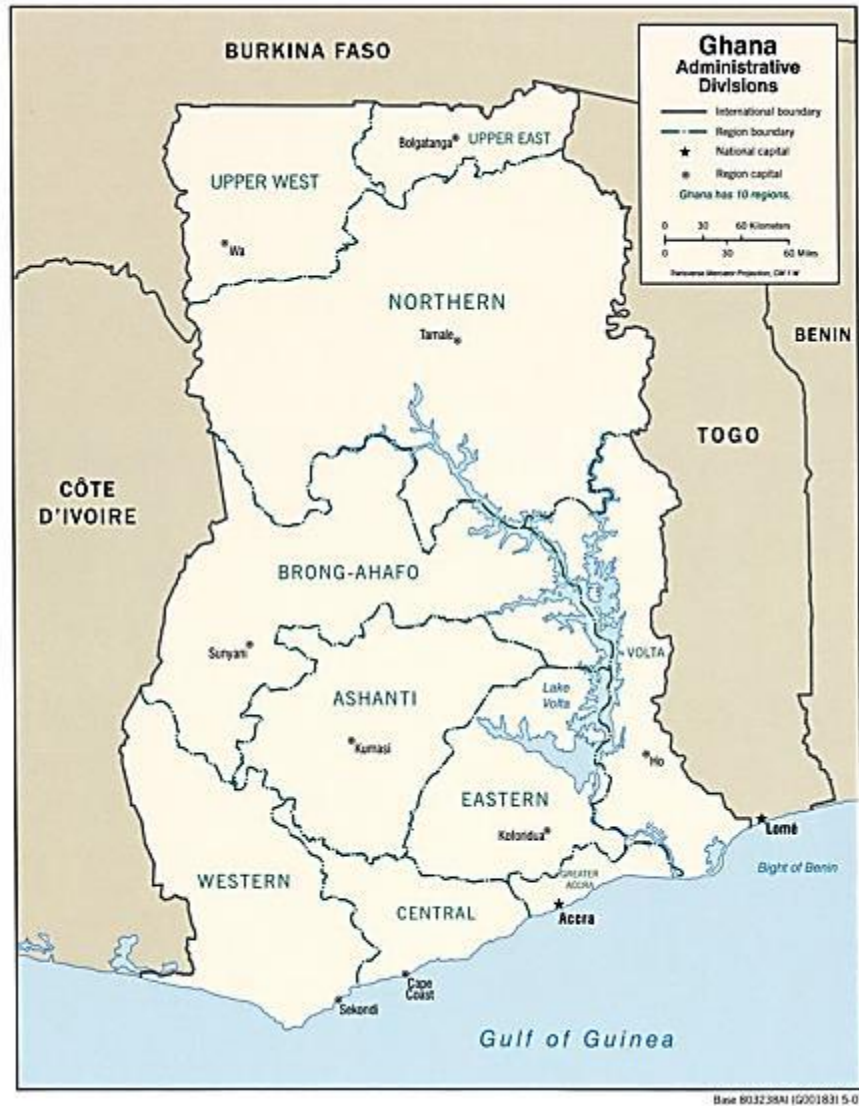


Figure 1.3: Map of Ghana and locations of neighbouring countries EC, 2009

Ghana lies in the equatorial belt between 15° North and 15° South parallels which is the next most favourable region for the purpose of solar energy application (the most favourable region with the greatest amount of solar energy is found in two broad bands around the earth between 15° and 35° North and South parallels). There are about 2500 h of sunshine per year with very little seasonal variation. Minimum irradiation ranges from 3–5 kWh/m²/day throughout the year (Atsu, 2016; Nazeeruddin, Baranoff and Gratzel, 2011).

Ghana's location in this region makes it natural that the application of solar energy should be given priority. It has been observed that Ghana's reliance on hydro energy and fossil based fuels for electrical power generation has been far too long for the country to start making use of its solar resource potential (Atsu, 2016; Adanu, 1994).

As reported by Energy Commission (2009), the southern part of the country is comparatively warm and humid and the northern part hot and dry, but temperatures vary with the season and altitude. In most areas, the highest temperatures occur in March and the lowest in August ranging between 32-34°C and 20-26°C respectively with the average temperature also ranging between 26°C- 30°C. In general, two rainy seasons occur in Ghana from April to July and from September to November.

The northern parts of Ghana however, experience the rainy season from April through to September. The annual rainfall varies between 2200 mm and 900 mm from the south to the north and about 700 mm along the eastern coastal belt. A dry desert wind, normally referred to as harmattan, blows from the northeast from around December to March (Energy Commission-Ghana., 2009).

The 2010 Population and Housing Census put Ghana's population at 24,658,823 (GSS, 2012). Agriculture dominates the nation's economy; the main crops are cocoa, rice, coffee, cassava (tapioca), peanuts, corn, sheanuts, bananas. Timber is also grown. Agriculture employs between 56 and 60 percent of the working population (National Development Planning Commission (NDPC, 2005). It is a priority sector in the country's poverty reduction strategic plan and has the potential to propel the economic growth and structural transformation of the nation in order to maximize the benefits of accelerated growth. (NDPC, 2005). Apart from agriculture, there are a lot of natural resources which also contribute a great deal to the development of the country. These are: hydro power, petroleum, gold, timber, industrial diamonds, bauxite, manganese, rubber, silver, fish, salt and limestone. Ghana is the second largest exporter of cocoa after la Cote d'Ivoire. Other commodities such as gold and timber are exported in a large quantity. There are a few industries including mining, aluminium smelting, food processing, cement manufacturing, light manufacturing and commercial ship building that can also be found in the country.

On 6th March, 1957 and 1st July, 1960 Ghana attained Independence and Republic status respectively from Britain. Since then there had been a series of military rulers and three democratic governments. However, from 1992, Ghana has been practising stable constitutional democracy and has held six successive elections (each following a four year term) for both the Presidential and Parliamentary elections in the fourth (4th) Republic.

1.3 Statement of the Problem

Entsua-Mensa-Mensa et al., (2007) and CWSA (2012) have reported that Ghana government's goal was to attain national potable water coverage of 85 % by 2015. However, by the end of 2015, this target has not been achieved. The principle of considering water as an economic resource or good generated a lot of campaigns against water privatization and protests in developing countries. One such protest had been staged in Ghana dubbed: "The Accra Declaration on the Right to Water" of May, 2001. The protesters argued that water is a public good, a heritage and a right; and that the community management of water supply should be an alternative to, or it should complement private-sector provision. (Entsua-Mensah et al., 2007; Gbedemah, 2010). This argument may be in favour of rural communities because according to Burkhartzmeyer (2008), many of the people in rural Ghana are subsistence farmers who rely on intermittent sources of water for their domestic needs (Burkhartzmeyer, 2008). A typical example is the people in the Agotime-Ziope district where community water supply is limited.

This is one of the two districts carved from the former Adaklu-Anyigbe district which has a population of 28,013 people (GSS, 2014b) and is the case study area for the current research. The communities depended upon a number of rivers and other streamlets, nevertheless, the rivers do not provide all year round water supply. During the dry season, the water levels reduce and some rivers and streams dry up completely; as a result, water and sanitation have become major development concerns of the District. The potable water coverage reported for the then Adaklu-Anyigbe district is 21 per cent (Agotime-Ziope District Assembly, 2013) which is inadequate. Furthermore, most water facilities, mainly boreholes (fitted with hand pumps) and hand dug wells found in the district at the time when the proposal for the current study was being developed (2009/2010) were dysfunctional. A number of them have been abandoned and left in the bush. Those water facilities that could be found in the heart of some of the communities were also abandoned because of dry yield (borehole without water) or there was some problem with the water itself (water became salty and hard). As if that was not enough, the rivers and streams that run through some of the communities were not maintained properly since people walked into the river to collect water, defecated and washed around the banks thereby allowing human excreta and soapy water to drain into the river and streams.

Meanwhile the Agotime-Ziope district is endowed with abundant sunshine all year round. The average sunshine duration is between 5.0-6.5 hours per day with solar insolation ranging 4.0 and 5.8 kW/m²-day but no single solar PV system was installed in any of the communities within the district at the time when the proposal for this research was developed. Also the grid extension did not reach most of its isolated communities. These revelations necessitated pragmatic action to solve the District's water problem because water is a basic necessity of life. The need to conduct this research into the situation to find a lasting solution to the problem therefore became imperative.

As stated above, energy for pumping dominates any discussion on water production and the selection of appropriate technologies for the provision of potable water especially to rural areas therefore becomes a necessity. Omer, (2001) notes that, the energy sources commonly available for rural water pumping are human or animal power, electricity and oil. He argues that even though diesel and electric pumps may be attractive, difficulties in securing regular energy supplies as well as facilities required for maintenance may limit their application. It follows therefore that the technology to adopt must be reliable, easy to operate unattended or by less skilled persons, it should require no fossil fuel and very little maintenance which is the characteristics of rural dwellers. Thus, wind and solar PV powered facilities look attractive.

Apart from the coastal belt of Ghana where wind speed is appreciable (far more than 3 m/s) the national average wind speed is 1.4m/s (Energy Commission, 2009). With this low speed, wind turbine for water pumping may not be suitable. Solar PV is likely to be a better technology for water pumping in Ghana because even the minimum insolation values of 3.1-5.8 kW/m²-day for the Middle Forest Zone of Ghana is adequate for the PV application. It was against this background that for the current study, solar photovoltaic energy has been considered for water pumping in rural locations of Ghana using communities in the Agotime-Ziope district as case study. Rohit et al (2013) note that using water pumps powered by photovoltaic systems has advantage of low maintenance, ease of installation and reliability; also there is matching between the powers generated and the water usage needs. They added that water tanks can be used instead of batteries in the systems (Rohit et al., 2013). Other researchers also explain that the PV has no moving parts in the solar conversion process, and hence wear and tear is eliminated. Also, the PV is modular and so can be connected in arrays to achieve the power requirements (McNelis et al., 1988; Thomas, 1992).

Although aspects of water quality are considered, the current research does not treat healthcare and sanitation in detail.

1.4 Aim and Objectives

The push by government to increase the take-up of renewable energy was not realised on the ground in Ghana. As noted by Bhattacharyya (2013), the preferred mode of rural electricity distribution in Ghana is by grid extension but generation capacity shortage affects the supply of reliable power. It was against this backdrop, solar PV water system has been proposed as a pragmatic technology to solve the water problem in the rural locations of Ghana. The aim is:

To assess the potential of solar energy for water pumping in rural locations of Ghana.

The specific objectives of the research are:

1. To carry out case studies of water abstraction in a number of remote villages of Ghana
2. To identify the economic, cultural and technical factors that influence water abstraction in the rural locations of Ghana in general, and with the use of solar PV in particular.
3. To design and evaluate a solar PV water system
4. To develop a market and financing frameworks for a solar PV water system for rural Ghana.

The aim and objectives may help to answer the following broader questions: what factors influence the adoption of solar PV technology for water pumping in rural Ghana, how will a solar PV water system perform in a typical remote community in Ghana and how cost effective is a solar PV water system for rural Ghana?

1.5 Structure of the Thesis

Table 1.2 summarises the structure of the thesis. The thesis is divided into eight chapters: Chapter 1 has introduced the context of the problem; Chapter 2 reviews the energy and water supply literature; Chapter 3 describes the approaches and methods used in the research while Chapter 4 presents quantitative results obtained by the use of questionnaire and chapter 5 the qualitative results on seven specific cases. The PV system design, installation and evaluation are treated in chapter 6. Chapter seven (7) presents discussions of all the results and generic

frameworks, implications for Ghana and more widely for developing countries. Chapter eight (8) summarises the research, provides conclusions, and offers recommendations.

Table 1. 1: Structure of the Thesis

	CHAPTER AIMS	ACTIVITIES	OUTCOMES
1	INTRODUCTION		
	To provide overview on energy and water supply and a guide to the thesis structure	Presented overview on water and energy; a brief background of Ghana, aim and objectives; and the thesis structure	Need for rural water and energy supply; Aim and objectives; Thesis Structure
2	LITERATURE REVIEW		
	To explore the research context, identify and address the knowledge gap existing in PV water supply in rural Ghana	Reviewed literature in and around the field, identified and addressed the gaps and made recommendations	Gaps in knowledge Validation of the aim and objectives of the research
3	RESEARCH DESIGN AND METHODOLOGY		
	To consider relevant research approaches, identify and select suitable methods which fit the current study	Systematically considered, selected and used suitable research methods regarding data collection and analysis	Research Design and Methods
4	PRESENTATION OF QUANTITATIVE RESULTS		
	To present and analyse the results derived from the quantitative study by use of the questionnaire	Collected and analysed quantitative data using questionnaire and SPSS respectively.	Quantitative results Obtained from using questionnaire
5	PRESENTATION OF QUALITATIVE RESULTS		
	To present and analyse the results derived from the qualitative study by use of interviews and observation	Collected and analysed qualitative data using interview guides and those from literature	Qualitative results obtained from interviews and observations
6	DESIGN, INSTALLATION AND PERFORMANCE EVALUATION OF SOLAR PV WATER PUMPING SYSTEM		
	To design, install and evaluate PV water system in Kporta community of Agotime-Ziope district	Selected Grundfos PV system; used it for the design; and installed the system. Also evaluated its performance	PV water system installed Results of both qualitative and quantitative studies on PV system in Kporta
7	DISCUSSION OF RESULTS AND DEVELOPMENT OF FRAMEWORKS		
	To discuss all the results derived from the study and use them to develop frameworks for PV adoption	Discussed all the results derived from the study (from the field and literature). Developed two frameworks	Two Models developed: Market Model Financial Model
8	CONCLUSION AND RECOMMENDATIONS		
	To draw conclusion on the research findings, make recommendations to stakeholders in the PV industry and suggest future works	Conclusions have been drawn; recommendations made and areas for future research suggested	Conclusions; Recommendations and Suggested areas of future research

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

Solar photovoltaic water supply systems are new technologies that are gaining acceptance all over the world but with some challenges confronting its diffusion and adoption. This chapter reviews relevant literature on the energy and water supply chain for rural communities. The implications associated with the use of the conventional energy sources (such as the grid and energy derived from fossil fuels) for water supply and the effects on the environment and the socio-economic lives of rural people have also been considered. Furthermore, the sources and quality issues of water for human consumption have been treated; the chapter has also dealt with renewable energy resources and technologies in general and solar photovoltaic energy in particular as the chosen technology for rural water supply in Ghana.

2.2 Sustainable Development and Technology Diffusion

Sopian et al. (2011) note that sustainable development demands a sustainable provision of energy resources that should be accessible at reasonable cost; also the resources must be used for all required tasks and still have positive influence on society. They articulate that, the demand for energy in recent times is met by fossil fuels which combustion has caused negative impacts (acid precipitation, stratospheric ozone depletion, and global climate change) to the environment globally. In order to overcome this negative effects, Sopian et al (2011) suggest the implementation of sustainable, clean and safe energy policies that need to satisfy the energy demand of the 21st century.

The term, sustainable development, was first used in “Our Common Future”, which was a report published by the World Commission on Environment and Development in 1987. This report which is also known as the Brundtland report included the definition of sustainable development as *“development which meets the needs of the present without compromising the ability of future generations to meet their own needs”* Drexhage and Murphy (2010). According to Iiskog (2008), sustainability has since its emergence become increasingly the focus of developmental research. She added that sustainability concerns the distribution of resources between and among generations. Quoting Johansson and Goldenberg (2002), Iiskog says when the implications for the energy sector in particular, are seriously looked at, then *“sustainable energy development will require electricity services that are reliable, available and affordable for all on a sustainable basis world-wide”*. Sopian et al (2011) assert

that renewable energy resources appear to be most efficient and effective solutions, therefore be key energy sources for the future. However, Magal (1990) notes that the real contribution that renewable energies will make in the future will depend on a number of factors, which he listed as:

Availability of conventional sources, the prices of conventional fuels; the desire of the country to reduce the dependence on external sources for meeting its energy requirements; the development of technology for effective and economic utilization of new and renewable sources of energy. Other factors considered are; infrastructure for the production, distribution, utilization and maintenance of systems based on new and renewable sources; limitations such as land, animal population, climatic conditions etc., and awareness among various sections of the population about the importance of new energy sources and adjustment of life styles to use these new sources (Magal, 1990).

Figure 2.1 shows a schematic diagram of sustainable development. From the figure, it can be seen that the three pillars of sustainable development are social, environmental and economic sustainability. For the renewable energy systems as well as water delivery projects to be sustainable, these three pillars must not be disadvantaged. Details of the structure have been discussed in section 2.2.1 under appropriate technology as a means to facilitating diffusion and adoption of solar water projects.

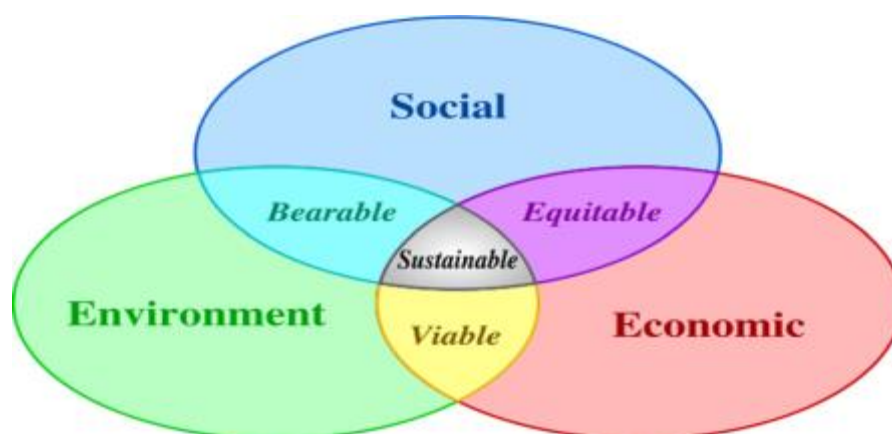


Figure 2. 1: Element of Sustainable development *Sopian et al (2011)*

2.2.1 Appropriate Technology for Diffusion and Adoption of Solar Water Projects

Murphy et al (2009) note that the challenges of fast growing population, urbanization, climate change, poverty, and widespread diseases will affect what are considered “appropriate” solutions in addressing needs in the water and sanitation sector. To them, flexible trial and error techniques, user participation, and multi-disciplinary collaborative learning are necessary to complement standard approaches so as to create ground-breaking solutions and empower poor communities to achieve their own development objectives (Murphy et al (2009).

Defining Appropriate Technology (AT) in context of developing countries, Murphy et al (2009) state that:

“Appropriate Technology is a strategy that enables men and women to rise out of poverty and increase their economic situation by meeting their basic needs, through developing their own skills and capabilities while making use of their available resources in an environmentally sustainable manner. The AT concept incorporates both ‘hard’ and ‘soft’ aspects of technology, meaning not only the physical tools, but the knowledge transfer mechanisms, capacity building and communication methods as well as social, cultural, and gender implications of technology implementation”(Murphy et al., 2009 :159).

Murphy et al. (2009) highlight ten criteria necessary to consider under appropriate technology if a project is to be sustainable. These are that the technology should:

- i. Meet the basic needs of users;
- ii. Be sound technology;
- iii. Be flexible technology,
- iv. Meet local capabilities by utilizing local materials and resources;
- v. Be affordable;
- vi. Be sustainable;
- vii. Encourage local participation;
- viii. Be culturally and socially appropriate;
- ix. Address gender consideration;
- x. Have appropriate technology transfer mechanisms;

In a similar observation, Shorts and Thompson (2003), quoting Dunn states that for a project to meet the requirements of appropriate technology (AT) it must have the following development objectives:

- i. To improve the quality of life of the people;
- ii. To maximise the use of renewable energy resources;
- iii. To create work places where the people now live; and that the solution chosen should satisfy the following criteria:
 - a) Employ local skills;
 - b) Employ local material resources;
 - c) Employ local financial resources;
 - d) Be compatible with local culture and practices;
 - e) Satisfy local needs and wishes;

Shorts and Thompson (2003) argues that any solution aims at using AT needs to consider and satisfy each of the five criteria listed above else there will be possibility of initiating unsustainable project. It is also noted that very often design and application of pumping systems do not take into consideration concerns relating to the social, economic, health and gender life of the people and this is what point (e) refers to as satisfying the local needs and wishes.

Clearly the two groups of researchers (Shorts and Thompson, 2003) and Murphy et al., 2009) are implying the same things and by combining their views together it will be possible to state that:

1. A technology that employs local skills as stated by Shorts and Thompson (2003) will be flexible and encourage local participation as indicated by Murphy et al. (2009); in the same way,
2. A technology that employs local material resources will also meet local capabilities by utilizing local material resources;
3. A technology that employs local financial resources will be affordable to the local people;
4. A technology that is well-suited with local culture and practices will culturally and socially be appropriate and address gender issues; it will be sound, most likely be sustainable and have appropriate technology transfer mechanisms; and

5. A technology that satisfies local needs and wishes will meet the basic needs of the users.

As explained by Murphy et al. (2009), basic needs of people mostly include food, shelter, potable water, sanitation, healthcare, clothing, education, employment and income generating ventures, these needs must be met if a technology which is meant for the people is to be appropriate. (Rohwedder, 1987; Evans, 1979; Ntim, 1988; Murphy et al, 2009). Inappropriate technologies would be those modern innovations that are directed towards satisfying wants and pleasures but not basic needs (Ntim, 1988; Murphy et al, 2009).

Seaton (2009) argues that technology transfer (as knowledge transfer) will be successful if the organization has not only the ability to acquire but also to assimilate and apply ideas, knowledge, devices and artefacts effectively. Organisations, and by extension communities, will respond to a technological opportunity only in terms of their own perceptions of its benefits and costs and in relation to their own needs and to technical, organizational and human resources (Seaton, 2009).

2.2.2 Policy Implementation towards Sustainable Solar PV Water Projects

Meier (2012) articulates six policy directions for sustainability of solar PV pumping system. These are:

Increase support to governments in creating enabling environments for rural water supply development.

Meier (2012) notes that because rural water access is difficult, support from donor agencies to governments need to be increased in creating an enabling environment for rural water projects. National rural development policies are thus required to adapt laws and to formulate measures such as licensing, concessions, permits, pricing mechanisms, capacity building, incentives, financing schemes, quality assurance, and technology advice in creating the enabling environment for rural water supply development.

Attract private investors to leverage available funds

Another policy direction suggested by Meier (2012) that will promote sustainable rural water supply is putting measures in place that will attract the private investor to leverage available funds. One such measure suggested is, a clear and independent regulatory framework offering adequate economic returns. This may make it possible to raise significant funds from the private sector and communities that would otherwise have to be sourced from public funds.

Develop Rural Water Supply Projects at Scale

Meier (2012) argues that although community-based management is still the reality in many countries for rural water supplies, when market-based practices are introduced and private companies operate the water supply schemes, maintenance and sustainable operation becomes less a problem.

Base Investment Decisions on Life-Cycle Costs of Rural Water Supply Infrastructure

Meier (2012) suggests that governments and donor agencies have to select water supply technologies based on proper life-cycle cost (LCC) analysis. Meier thus argues that PV water system is more economical than water systems powered by diesel technology in a growing power range due to the decreasing cost of PV technology and frequent breakdown of diesel engine. Consequently, the PV becomes the preferred choice (Meier, 2012). This observation supports an earlier argument made by EmCon (2006).

Consider the Whole Water Chain to Guarantee System Reliability

The water chain includes power generating point, pumping, storage and distribution. Meier (2012) states that the key problem affecting the system reliability is the fact that PV pumping programmes do not consider the final service as a whole, hence service reliability becomes negatively affected. The rest of the system in the water chain apart from the power generating point is much more prone to failure which is often the reason for a failed PV pumping projects. It is therefore necessary to consider the whole water chain to ensure the reliability of the system.

Envisage Larger Integrated Electricity and Water Supply Systems in Off-grid Areas

Meier (2012) notes that grid-parity of PV electricity supply has become close to a reality due to steady reduction in PV modules prices. This, coupled with rising prices for fossil fuels creates the application range within which PV technology can compete on economic terms to be broadened, particularly in off-grid areas. Meier suggests that an integrated system could be built, operated and maintained like any other infrastructure project; in this way, rural households can be treated in a similar way to urban dwellers.

2.3 Global Energy Need and its Impact on the Environment

Jacobson and Johnson (2000) note that the energy sector is subject to a set of parallel and interacting forces of change. The most important of such forces is awareness of the environmental consequences (acidification and global climate change effects caused by fossil fuels) of the conventional energy system. In support, Husain et al (2011) have also stated that

fossil fuel contributes to some detrimental phenomena such as environmental pollutions; coupled with this is fluctuating fuel prices, therefore renewable energy sources can be better options for the generation of green electricity (Husain et al, 2011). Gross et al. (2003) also note that the adverse effects of conventional energy sources on the environment has been a concern for governments all over the world, hence their emphasis on the use of renewable energy as important technologies for reducing energy related environmental problems, particularly CO₂ emissions (Gross et al, 2003).

The threat posed by nuclear disasters and problems associated with radioactive waste disposal have been other issues that receive much attention. Jacobsson and Johnson's (2000) earlier observation that as a response to the new awareness, a demand for 'green' energy has been developing, agrees with the observation made by Husain et al (2011).

Energy is essential for economic development and providing vital services that improve quality of life. Sopian et al. (2011) argue that it is required for meeting all of the basic needs of mankind and it shows clear correlation with the Human Development Index HDI. Jayarkumar (2009) argues that energy has an established positive correlation with economic growth. Energy has also been said to be an important tool for socio-economic development (Hayes and Schofield, 2002). It is required for the production of all goods and services.

The importance of energy as a factor in development has been supported by Mainali et al., (2012) who assert that electrification is a major preoccupation for developing countries as it is considered a requirement for development.

de Alegrı'Mancisidor et al. (2009) have reported that a direct relationship exists between prosperity (or wealth) and the increase in energy consumption but noted also that this relation is now under challenge. According to Koskimäki (2012), growing energy use is often regarded as a condition for economic growth, and linking this to South Sahara Africa (SSA), he argues that SSA countries could carve their own path to an energy efficient economy, not following the path that Europe for instance has taken, when the continent expanded its energy use and later painfully tried decreasing it. It is therefore evident that energy supply may promote growth and development.

Whilst the demand for energy keeps on increasing, fossil fuels (oil, gas, coal) are being depleted. Jennings (2009) points out that there is an unprecedented concern about fuel prices

and oil depletion coupled with concern about high level of global warming and how best to respond to it. He suggests a great reliance on renewable energy for power generation as renewable energy is seen by many as part of the appropriate response to these concerns (Jennings, 2009). Jayarkumar (2009) also notes that the unavoidable increase use of non-renewable energy along with a country's economic growth does not only threaten a nation's energy security but also promote its environmental degradation (Jayarkumar, 2009). According to Hayes and Schofield (2002), energy systems contribute most to the environmental burden being faced by the world, leading to rapid environmental degradation.

As observed by Chynoweth et al, (2000) and Vindis et al, (2007), the increasing demand for energy, rise in oil prices, exhaustion of fossil fuel and the growing concern for environmental issues have challenged researchers to develop a new technological processes to obtain cleaner and a more sustainable energy sources (Chynoweth et al, 2000; Vindis et al, (2007).

The provision of sufficient, reasonably priced and clean energy is a critical requirement for alleviating poverty and improving productivity. Hayes and Schofield (2002) suggest this would be achieved by applying best practices in sustainable development to the energy sector. Therefore economic growth can be sustainable if it is fuelled by energy systems that are increasingly more efficient, less expensive and cleaner.

In their assertion, EIA (2009) and Jefferson (2006), renewable energy (RE) sources are the fastest growing energy source in the world and various projections indicate that these resources will have huge contribution in the future.

The European Photovoltaic Industry Association (EPIA) reported that climate change and the prospective of fossil fuel scarcity have strengthened the need to promote renewable energies (EPIA, 2011). In its observation, the EPIA sees the exploitation of solar photovoltaic electricity (PV) as playing a crucial role in helping the European Union meet its commitment in fighting climate change and ensure security of supply, reducing Europe's dependency on energy imports.

Razykov et al (2011) observed that Photovoltaic (PV) electricity is one of the best options for sustainable future energy requirements of the world. They further reported that as of 2009, the PV market has been growing at an annual rate of 35-40%, with PV production around 10.66 GW in that year.

Reported by the UNDP (2005), access to modern and suitable energy supply has been considered as a key enabler of poverty alleviation and sustainable development (UNDP, 2005). This access plays an essential role in the achievement of the millenium development goal (MDG) even though no such goal has been exactly defined for energy issues. Nissing and von Blottnitz (2010) therefore observe that it appears energy planning processes could be key promoters of environmentally sustainable and socially meaningful development, if focused sturdily on detailed socioeconomic development needs and linking these directly to renewable energy supply options. From the above arguments, it is clear that the quest for growth and development must be in tandem with the provision of clean and sustainable energy which is environmentally benign (Nissing and von Blottnitz, 2010).

Ottichilo et al. (1991) observe that there is a growing awareness that the increase in the amount of greenhouse gases (GHGs) being released into the atmosphere will have adverse effects on the global weather systems. They explain this effect will not be globally uniform but could differ significantly between geographical regions and vary between seasons and it will likely affect the natural resources. The key natural resource sectors that might be susceptible to changes in climate include agricultural crops, livestock, forests, water resources, coastal resources, fisheries, and wildlife (USA government, 1994). Compared to industrialized countries, African countries are said to be more vulnerable to the effects of climatic change (MNREA, 2003). Two reasons are given for this: the first reason is that the current economic and ecological crises have weakened the capacity of many countries to adjust to drastic economic and ecological changes. Secondly, most of the people in Africa depend on agriculture for their subsistence, which also depends a great deal on climatic patterns (Mkanda, 1995).

2.4 Impact of Climate Change on Sustainable Water Supply

Sustainable water supply takes into consideration the available water resource; these can either be surface water or groundwater depending on availability and demand, topography, hydrological formation of the ground, annual rainfall, characteristics of the ground aquifer and the type of proposed use or application (Argaw, 2004).

In a study conducted in Eastern Africa by AFREPREN/FWD (2012), it has been reported that, water supply in both rural and urban locations have been adversely affected by repeated

and persistent droughts and shorter rainfall periods attributed to climate change effects. This normally leads to rationing programmes to equitably distribute the available water.

Furthermore, climate change has had a toll on the water sector of Africa and other developing countries by causing rivers to get dry and warming the globe during a period of drought on one hand, with its attendant food scarcity and hunger; and on the other hand, it has caused land degradation resulting from prolonged heavy rains. The ability of solar PV pumps to supply potable water and water for livestock all year round enhances the resilience of the water sector to climate change (AFREPREN/FWD, 2012).

2.5 Rural Water Supply and Sanitation

“Water and Sanitation is one of the primary drivers of public health. I often refer to it as ‘Health 101’, which means that once we can secure access to clean water and to adequate sanitation facilities for all people, irrespective of the difference in their living conditions, a huge battle against all kinds of diseases will be won”. Dr. LEE Jong-Wook, Director-General, World Health Organization.

“We shall not finally defeat AIDS, tuberculosis, malaria, or any of the other infectious diseases that plague the developing world until we have also won the battle for safe drinking water, sanitation and basic health care.” Kofi Annan, United Nations Secretary-General.

The above quotes highlight the importance the United Nations attaches to rural water provision and sanitation especially in developing countries. The World Health Organisation, (2004) reports that 1.8 million people die every year from diarrhea related diseases mostly in developing countries. According to the report, 88 % of this disease is attributed to unsafe water supply, inadequate sanitation and hygiene. However, the diarrhea morbidity reduces within the range from 6 % to 25 %, as a result of improved water supply whilst improved sanitation reduces this morbidity by 32 % (WHO, 2004). It is also reported that absence of safe water for face washing led to visual impairment of 6 million people out of 146 million threatened by trachoma, but the ill-health due to trachoma could be reduced by 27 % with the use of access to improved safe water and better hygiene practice.

2.5.1 Water and Sanitation Issues

Rural water delivery has great challenges. Water.org (2017) reports that the lack of potable water has health, social and economic effects.

In terms of health, it is reported that women and children can lose up to a third of their daily food intake energy in collecting water. Socioeconomically, most African girls suffer from poor water and sanitation situation and many are kept at home to do domestic work; so class-room hours are sometimes used by school children in search of water. It has also been reported that about 266 million hours of women and girls' time are spent each day for collecting domestic water globally (Water.org, 2017) thus, families have less time for income generation and other quality of life matters. Collectively, the loss in productivity to the African economy as a result, is equivalent to US \$32 billion every year (Water.org, 2017). In the next sections, available sources and methods of water treatment are considered.

2.5.2 Sources of Water

There are basically two sources of water accessible to man (Singh, 2013), they may be surface water from rivers, streams, lakes and reservoirs (dam, pond) etc., or they may be underground water sources such as springs and wells (borehole and hand dug well). Rain water is also harvested.

2.5.2.1 Rain Harvested Water

Rainwater harvesting is a system for collecting and storing rainwater for later reuse. In communities where access to water for hygienic purposes is a challenge, such as in many rural communities, rooftop rainwater collection can make a significant contribution. Figure 2.2 shows a typical rainwater harvesting system with some pupils washing their hand under the tank (USAID Ghana WASH, 2014).

2.5.2.2 Dam

The term “dam” used in this context is an artificial reservoir on the land surface that stores sufficient amount of water. It is usually constructed by scooping a large portion of land to allow rain water and any moving water like a river to get collected in it. Sometimes the scooped land has embankment all round it. Depending upon the water holding capacity of the “dam” and the weather condition, the water in such a reservoir may go dry especially during dry season.



Figure 2.2: A typical rain harvesting system *USAID Ghana WASH, (2014)*

2.5.2.3 River and Stream

Rivers and streams are running waters that also serve as major sources of water supply for human use. Big rivers form the main source of water supply schemes in large cities whereas streams form the principal sources of water supply for rural communities in hilly places.

Rivers may be perennial or non-perennial in nature. While water flows in the former throughout the year, in the latter, water does not flow during the dry season except in rainy season. The nature of water accessible from rivers is generally unreliable because it contains lots of suspended, colloidal and dissolved impurities as already noted. The water in the rivers is often polluted by the people inhabiting the watershed. In some situations, when the town on the upstream discharges sewage into the river, the water becomes highly contaminated and thus requires elaborate treatment before it can be supplied for use. During rainy season, it is possible that high floods come into the river. When this happens, the excess flood water is stored by building a dam or weir across the river; this stored water is used during the period when the demand exceeds the supply (Singh, 2013).

Just like the rivers, streams also collect impurities such as sand; and minerals etc get dissolved in them making the water from the stream harmful, there is therefore the need to treat water from the stream before it is supplied for use. Dams and weirs are constructed to store excess water during rainy season when the streams are flooded (Singh, 2013).

2.5.2.4 Groundwater prospecting

Groundwater is accessed through drilling of borehole or hand dug well. Sometimes the underground water is accessed in a form of natural springs. A well is an artificial arrangement for exploitation (intake, capturing, pumping, monitoring, sinking, seeping or reinjection) of ground water (Wilo Se, 2012). There exists a variety of designations for categorising wells based on specific criteria, such as by the type of generation (shaft, borehole wells etc.), by the size (excavated wells), of the construction (pipe wells) and by the type of water extraction (deep wells). A comprehensive list of such categorisation can be found in Wilo Se (2012).

Drilling and construction of a borehole requires hydro geological surveying of the site where the borehole is to be sunk, drilling and construction work itself, conducting pumping test and water quality analysis. Where yield and quality of the water are not likely to meet acceptable values due to difficult nature of the geological environment (geological environment that is difficult in terms of ground water prospect) hydro fracturing method is employed. Hydro-fracturing is to pump highly compressed air to crack and open up underground rock of the aquifer so as to increase the yield. A typical drilling rig is as shown in figure 2.3 adapted from Wilo Se, (2012). Groundwater is therefore abstracted from a borehole by means of hand pump or mechanised pumping system mounted on the borehole. Water from hand dug well is usually abstracted by hand lifting with bucket and rope.

2.5.2.5 Bottled and Sachet Water

Potable water collected from the distributing mains are sometimes treated again and stored in bottles and small rubber sachets. In Ghana, they are respectively referred to as “bottled water and “pure water.” In some cases, underground water is collected and treated directly before bottling or storing it in small rubber sachets; mineral water is example of such water. The use of this type of potable water in the country has gained massive acceptance especially in the urban places. This is so because it is handy, and can be stored in the refrigerator to cool.



Figure 2.3: A typical drilling rig *Wilo Se* (2012)

2.5.3 Rural Water Quality

Water from rivers and lakes is accessed through intake and treatment works (sedimentation, filtration, disinfection and miscellaneous treatments) after which the treated water goes through distribution system and finally to the consumers (Kamala and Kanth Rao, 1999). During the process of sedimentation, in a typical water supply scheme, suspended solid particles are allowed to settle down in a sedimentation tank and coagulants are sometimes added to speed up the settling process. The water is then allowed to pass through filter beds consisting of large sand layers so that fine suspended solids and some bacteria will be removed. Disinfectants such as chlorine in the right proportion are added to kill the rest of the bacteria. The purified water will then be stored in a reservoir ready to be distributed to the consumers under gravity or pumped through distribution pipes.

There are many reasons for treating water before supplying it to communities for drinking purposes. Waste water from some of the industries is allowed to drain off into rivers; the

water is polluted making it not safe for human consumption. Rainwater is the purest form of water, but when it falls onto the ground, it collects a lot of dust and dissolves certain gases forming acids. It also collects decayed biomass which forms organic acids. While surface water is most of the time turbid and contains substantial quantities of bacteria, groundwater is clearer, from sanitary point of view and of better-quality. In spite of these superior qualities of groundwater, it contains higher amount of salt than surface water because as water moves slowly through the substrata for prolonged periods the mineral content becomes higher in the underground water. As a universal solvent, water is able to dissolve a lot of minerals it comes into contact with. Michael and Khepar (1989) note that the quantity and the composition of the dissolved minerals in natural water depend on the type of rock or soil in contact with it or through which the water seeps into, and also the duration of contact. The water quality also changes from one place to another, varies from stratum to stratum, and from season to season. They added that these factors must be taken into consideration when determining the suitability of water for the purpose it is to be used.

Kamala and Kanth Rao (1999) also point out that water may contain certain salts and minerals in less (i. e. in acceptable) quantity that impart fine taste and assist in digestion. Thus it is important to test the water (and if necessary, treat it) before distribution to the consumers. They identify the following tests to be conducted on the water to determine its quality:

2.5.6.1 Physico-Chemical Analysis

The physical tests are the analyses of water colour, taste and odour, temperature and turbidity; they have to do with indicating aesthetic quality and performance of various treatment units. The chemical tests have to do with indicating the quantity of chemicals present in the water and the amount of pollution in it. The analyses include determination of total solid, hardness, chlorides, dissolved gases, pH value or hydrogen-ion concentration, nitrogen and its compounds, metal and other chemical substances. Physico-chemical analysis is therefore necessary to be conducted on water used for domestic purposes especially for drinking.

2.5.6.2 Bacteriological Analysis

Although bacteriological analysis of water does not give much information of the isolated history of the water as done by chemical analysis, it provides highly reliable information on

the immediate causes of water pollution. Singh (2013) therefore argues that conclusion on water purity must not be drawn on results of chemical analysis only, since chemically pure water will show the presence of pathogenic bacteria during bacteriological analysis. Bacteriological tests, according to Kamala and Kanth Rao (1999), show the presence of bacteria producing pollution and whether the water is safe or not for drinking purposes. Singh (2013) pointed out that intestines of human beings and warm blooded animals contain harmful bacteria which are excreted with faeces and can be found in sewage which pollutes water. Bacteria as microscopic organisms may be harmful (pathogenic bacteria) or harmless (non pathogenic bacteria). The harmful ones cause typhoid, cholera, dysenteries, etc and thus must be removed from water supply. Detecting pathogenic bacteria can be burdensome so a simple test that enables determination of the presence of intestinal organisms (i.e. coliform group of bacteria) is usually conducted (Kamala and Kanth Rao (1999). When the presence of the coliform group of bacteria is detected, then there is a high probability that the pathogenic bacteria are also present. Table 2.1 adapted from Wilo Se (2012) illustrates the constituent materials of water analysis which are relevant for pump configuration and users. An acceptable level of each constituent material is measured against the World Health Organisation's standard value.

Table 2.1: Constituent Materials of Water Analysis Relevant for Pump Configuration
CONSTITUENT MATERIALS **SIGNIFICANT FOR PUMP DESIGN**

Colour	Brown colouration indicates a high iron content resulting in iron corrosion
Turbidity	May indicate suspended particles of a high sand content
Electric conductivity	Conductivities in excess of 1000 μS indicate that the water will be aggressive towards materials such as cast iron and lower-specification (stainless) steels
pH value	Indicates the corrosiveness
Sulphate	From 200 mg/l there is significant corrosiveness in relation to materials such as cast iron and unalloyed or low-alloy steels
Chloride	From 150 mg/l there is significant corrosiveness in relation to materials such as cast iron and unalloyed or low-alloy steels
Iron	From 0.2 mg/l there is particular tendency to sedimentation of iron ochre
Manganese	From 0.1 mg/l there is particular tendency to sedimentation of manganese dioxide
NH_4^+ , Cl_2 , H_2S , NH_3 , sulphides, humic acids, hydrocarbons	Aggressive towards cast iron and in some respects also bronze

Wilo Se (2012)

2.6 Energy Resources

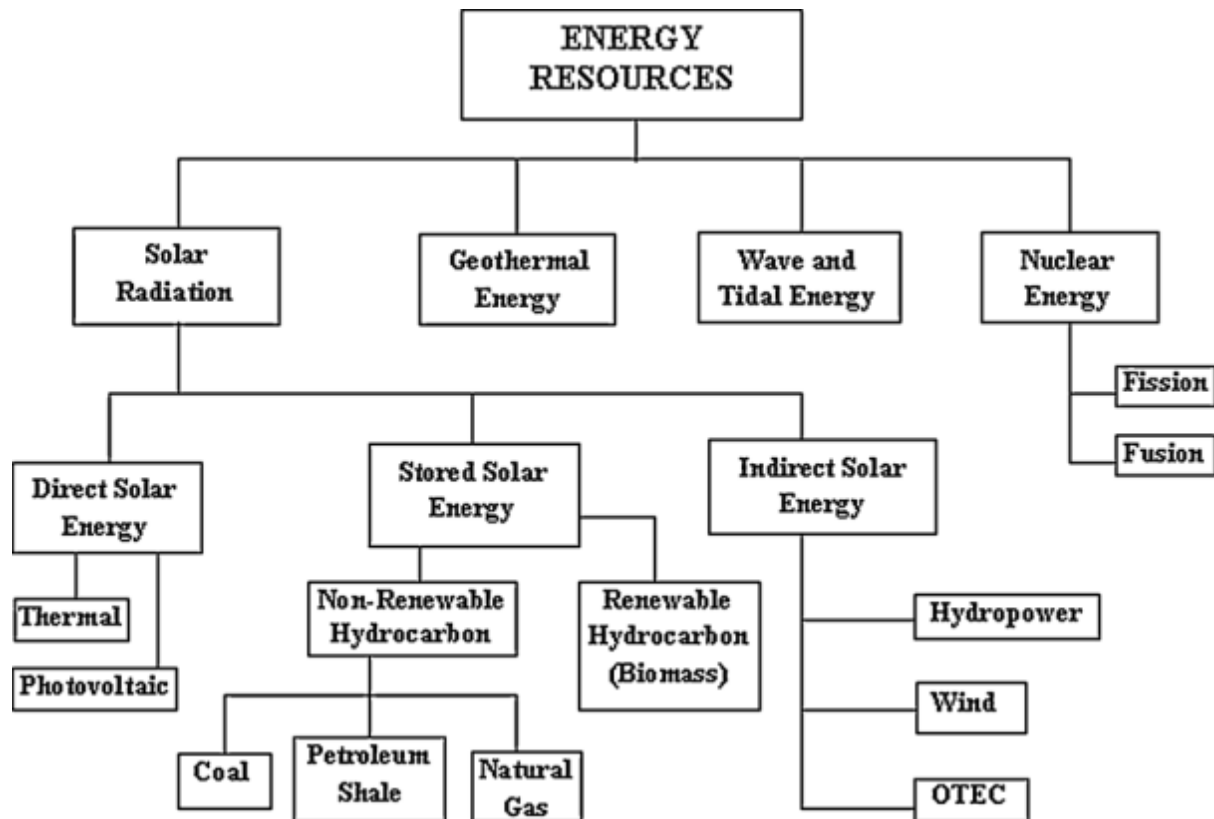


Figure 2.4: Classification of energy sources *Sopian et al. (2011).*

Energy resources can be classified as shown in figure 2.4. Sopian et al (2011) highlight the energy resources and show that they are divided into solar radiation, geothermal, wave and tidal, and nuclear. Solar energy comprises direct solar, stored solar and indirect solar energy. The two forms of energy classified under direct solar are solar PV and solar thermal. Stored solar energy comprises non-renewable hydrocarbon such as petroleum, natural gas, coal and shale and renewable hydrocarbon such as biomass and biogas. Hydropower and wind energy are the two forms of indirect solar energy.

2.6.1 Renewable Energy Sources

Quoting Twidell and Weir (1986) and Sorensen (2000) respectively, the Open University defines renewable energy as '*energy obtained from the continuous or repetitive currents of energy recurring in the natural environment*'; and as '*energy flows which are replenished at the same rate as they are "used"*'. Based on the definitions, the following sources of energy have been classified as renewable: direct solar energy (photovoltaic and solar thermal);

bioenergy (energy crops and wastes); Hydroelectricity; tidal power; wind energy; wave energy and geothermal energy (Open University, 2004).

Solar energy is produced when radiation from the sun is converted into useful energy directly using various technologies. When the radiation is absorbed in a solar collector it can provide hot water or heat a space. Such spaces (buildings) to be heated can be designed with passive solar features that improve the contribution of solar energy to the space heating and lighting requirements. It is also possible to concentrate solar energy by mirrors to provide high-temperature heat that can generate electricity. Using photovoltaic panels (a combination of modules made from semiconductor cells), solar energy can convert the sun's radiation into electricity.

One of the most prominent features of renewable energy sources is the diversity of technologies and resources. Gross et al (2003) present a general idea about the leading resources and the technologies (shown in table 2.2) for harnessing them. They note however, that the figures in the table 2.2 are illustrative of the energy that may possibly be extracted for utilisation by means of known technologies and making room for physical constraints.

Table 2.2: Global Renewable Energy Resources

Resource	Scale of Technical Potential (useful energy output) (TW h/year)	Energy Conversion Technology Options
Direct solar	12,000–40,000	Photovoltaics Solar thermal power generation Solar water heaters
Wind	20,000–40,000 (onshore)	Large scale power generation, small scale power generation and water pumps
Wave	2000–4000	Numerous designs
Tidal	>3500	Barrage, tidal stream
Geothermal	4000–40,000	Hot dry rock, hydrothermal, geopressed, magma (only hydrothermal currently viable)
Biomass	8000–25,000	Combustion, gasification, pyrolysis, digestion, for bio-fuels, heat and electricity

Gross et al (2003)

Table 2.3: Installed Capacities and Output of ‘new’ Renewables

Technology	Capacity (MW) ¹	Approximate Annual Output ² (TW h/year)
Biomass (modern)	35,000	185
Wind	20,000	50
Geothermal	8,200	44*
Small Hydro	3,000	15
Solar PV	1,200	1
Solar Thermal	35,002	0.2
Total	68,550	356
	Capacity (GW)	Output (TW h/year)
Current world electricity	3,000,000	15,000

¹*Sources: UNDP/WEC (2000) and Wind Power Monthly (2001)*

²*Source: Gross et al (2003) and * UNDP/WEC (2000)*

Such figures according to Gross et al (2003) are inevitably approximate and depend upon assumptions about conversion efficiencies, competing land-use and so on.

Obviously, renewable technologies are varied in terms of both commercial and technological maturity. Some (solar and wind energies) are close to competing with fossil fuels and may be cheaper if environmental externalities are included, but others (tidal and wave) are much further from market feasibility. Gross et al. (2003) suggest that appropriate policies need to be put in place to allow those options and applications that are close to commercial viability to flourish, at the same time ensuring that options which hold promise for the longer term are developed through their infant stages (Gross et al, 2003).

2.6.2 Solar Energy Resource

The sun is made up of ionized gases (80 % hydrogen and 20 % helium) with a high temperature of 5762 K. The total energy it emits is 3.85×10^{23} kW of which only 1.7×10^{17} W is intercepted by the earth (Dufie and Beckman, 1980; Omer, 2001). However at the mean sun-earth distance of 1.496×10^{11} m, only 1367 W/m^2 radiant energy (referred to as solar constant; G_{sc}) becomes available which further reduces to approximately 1000 W/m^2 by the time the energy reaches the earth’s surface (Dufie, and Beckman, 1980; Morales and Busch, 2010). This reduction in energy is as a result of the elliptical nature of the earth’s orbit around the sun which is almost spherical with a diameter of 1.392×10^9 m; hence variation in both geographic location and time of the day. The greatest radiation appears when the sun is straight overhead (in a clear day) known as solar noon but reduces and becomes lowest

during early morning and late afternoon. Figure 2.5 shows a typical pattern of solar radiation during a clear day.

Two other concepts worth defining are solar irradiance and solar insolation. Solar irradiance is the amount of solar energy received by, or projected onto a specific surface. It is also expressed in units of kW/m^2 and is measured at the surface of the material. In the case of a PV-powered system, this surface is the solar panel. Solar insolation is the amount of solar irradiance measured over a given period of time. It is determined by summing the solar irradiance over time, and is usually expressed in units of $\text{kWh/m}^2\text{-day}$. It is typically quantified in peak sun hours, which are the equivalent number of hours per day when solar irradiance averages 1 kW/m^2 . Other units are (MJ/m^2) or Langley (L), for the given period such as a day or hour. $1 \text{ kWh/m}^2 = 1 \text{ peak sun hour} = 3.6 \text{ MJ/m}^2 = 0.0116 \text{ L}$ (CANMET, 1991). “Peak sun hours” is a useful measure when sizing photovoltaic systems since the panels are usually rated in peak Watts (CANMET, 1991).

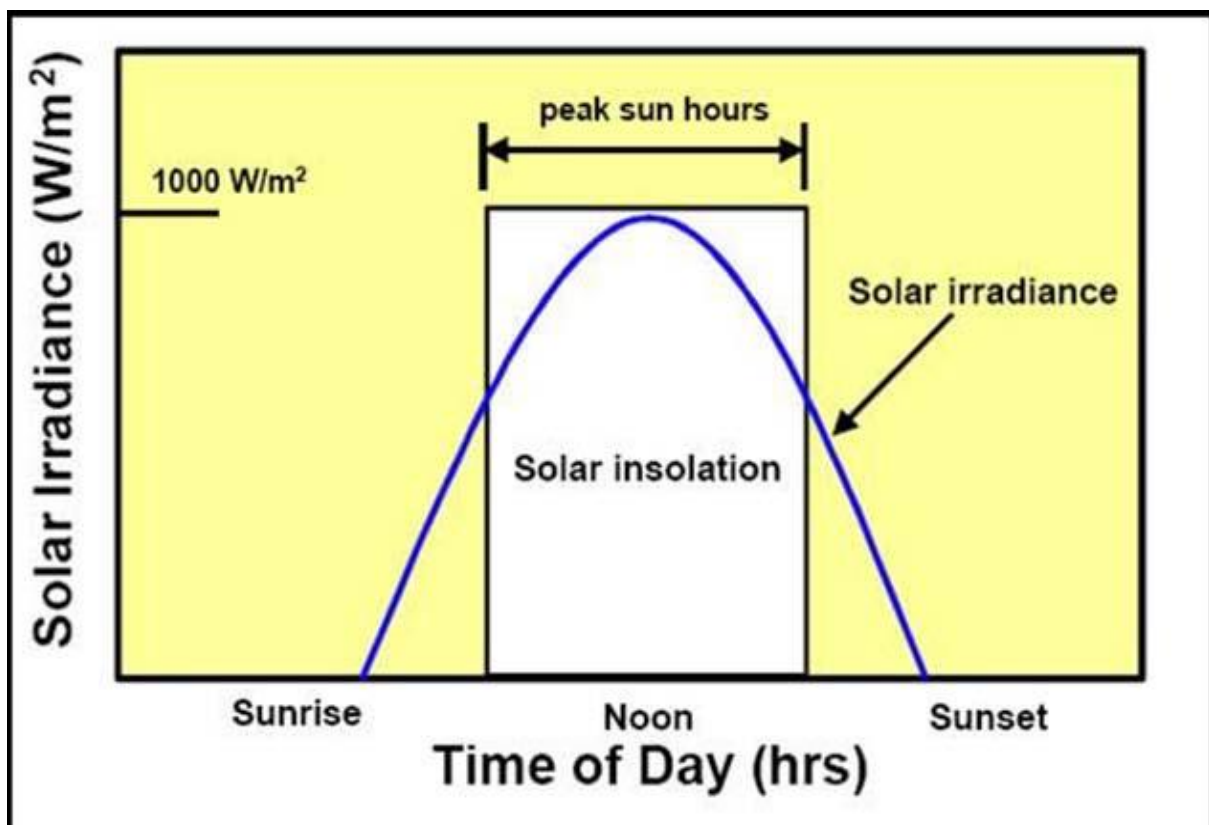


Figure 2.5: Solar irradiance and peak sun hours (Morales and Busch, 2010).

The result of the earth’s motion and atmospheric effects at various locations have led to essentially two types of solar insolation data; namely daily and hourly data. Daily values of

insolation are usually presented as monthly averages for different latitudes, tilt, and specific locations (to allow for differences in weather effects) (Morales and Busch 2010).

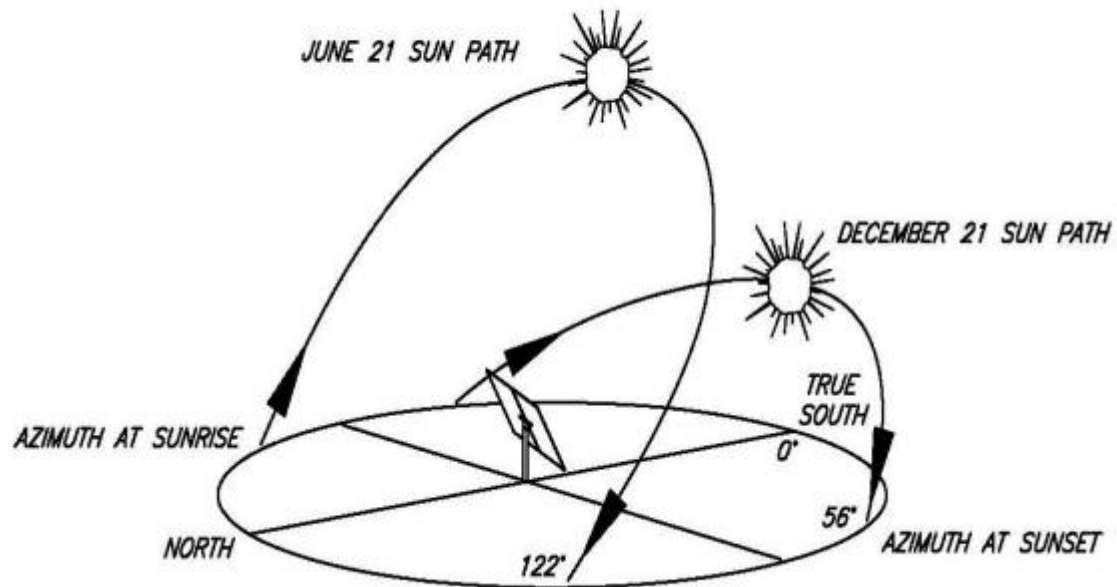


Figure 2.6: Example summer and winter sun elevation and angle *Morales and Busch, 2010*).

The solar radiation intensity decreases when it travels through the earth's atmosphere not only because of variation in geographical location and the time of the day but also as a result of absorption and scattering by the gases comprising the atmospheric aerosols, airborne particles, clouds and water vapour. Clouds, which consist of large water drops, produce very high attenuation of solar radiation. Other factors that cause the available energy to vary with the latitude and time of the day and year are the earth's rotation and tilt. Figure 2.6 is a diagram showing elevation, azimuth and tilt angles of the sun in relation to the earth at summer and winter. The global radiations reaching a location are made up of both the beam (direct) and diffuse (hazy) components as the result of the absorption and scattering effect.

2.6.2.1 Instruments used for solar radiation measurement

There are several instruments for measuring solar radiation levels. Direct beam solar radiation is usually measured by a pyrheliometer, and global solar radiation, a pyranometer (Dufie and Beckman, 1980; Magal, 1990). Diffuse radiation can be measured if the

pyranometer is shaded. Silicon based sensors are used to measure incidence radiation. This type of instrument measures the intensity of solar radiation directly when the electrical characteristics change; they are described as photoelectric devices (Argaw et al., 2003). It is therefore necessary to have the information on the quantity of the solar radiation available at the location before planning and designing the solar energy system to be used.

2.6.3 Solar Cell Technology

Photovoltaic cells are the basic building blocks of any photovoltaic modules. Each module contains solar cells permanently wired together in series and parallel to form a single electric power unit. The unit is packaged together so as to protect the cells from the environment while permitting sunlight to reach the active surfaces of the cells. Most modern photovoltaic devices use silicon as the base material, mainly as mono-crystalline or multi-crystalline cells; more recently, they are also used in amorphous (non-crystalline) forms. Cadmium sulphide and gallium arsenide (which can act as an insulator and conductor) are also used. Figure 2.7 shows solar cell (a), solar module (b) and array of solar panels (c).

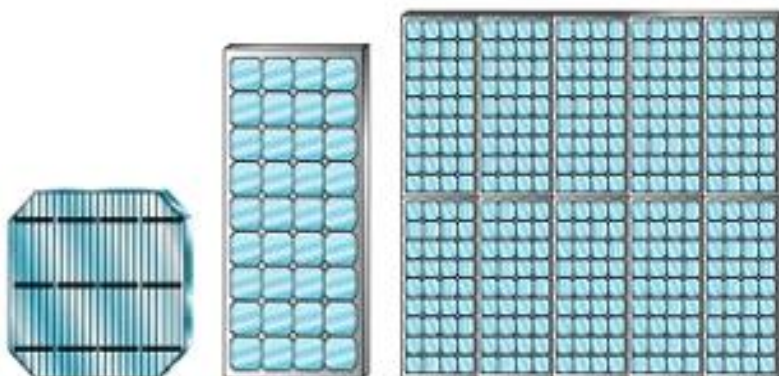


Figure 2.7: Solar cell (a), modules (b) panels (c) *Morales and Busch, 2010; Peltm, 2012.*

Table 2.4: Types of PV cells and their efficiency *Morales and Busch, 2010*

Type of Cell	Efficiency Range	Comments
Mono crystalline	14 to 16 %	Highest price, affected by temperature
Polycrystalline	12 to 14 %	Medium price, affected by temperature
Amorphous Silicon	8 to 9 %	Medium to low price, not affected by temperature

2.6.4 Decentralised Energy Systems

Conventionally electricity has been supplied through a grid system which conveyed and provided electricity from centralized power stations. Bhattacharyya et al (2015) however note that, with the advent of new generation technologies, there has been a switch from central

stations leading to an alternative decentralized approach to supplying electricity. The decentralised system can be grid-connected or off-grid (stand-alone) options.

2.6.4.1 Solar PV Stand Alone System

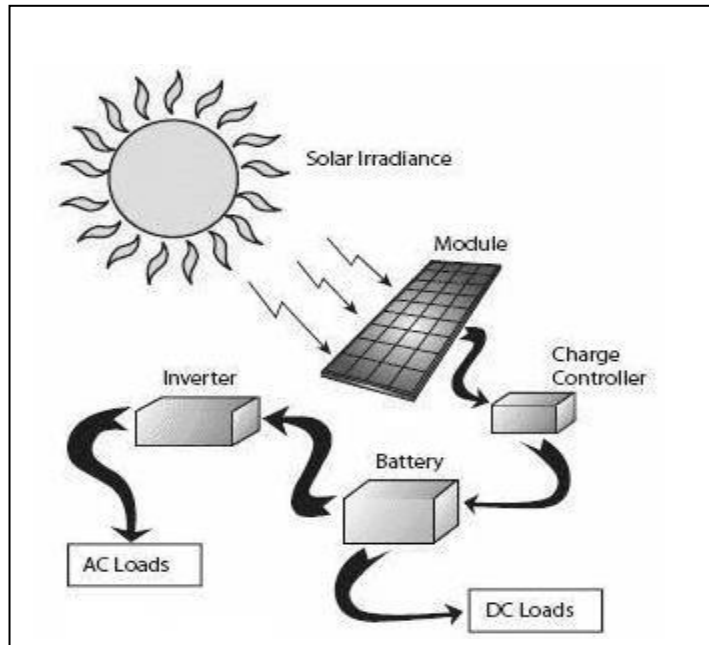


Figure 2.8: Schematic diagram of solar PV stand-alone system Abu-Jasser (2010)

Solar photovoltaic technologies include off-grid solar home system, PV for grid integration, public/street lighting, vaccine refrigeration, irrigation and water pumping. As noted by Gupta and Garg (2013), the benefits of power generation from these sources are widely accepted. They are essentially inexhaustible and environmentally friendly.

Bhattacharyya et al. (2015) have stated that an off-grid electricity supply can be in the form of individual product-based and also as collective network-based solutions. The first involves the sale of a product or a service that enables individual users to produce a small amount of electrical energy (often of low voltage) to meet some basic household demands (lighting, television, a radio, a fan etc.). The second category solutions serve more than a single individual user and supply electricity to the users generally by generating electricity locally or by buying electricity from other sources and distributing it among the clients (Bhattacharyya et al, 2015). Figure 2.8 adapted from Abu-Jasser (2010) illustrates a schematic diagram of a solar PV stand-alone system. The solar PV standalone (off-grid) is the system installed for the current study.

2.6.4.2 Hybrid PV System

The need for hybrid systems is necessitated by the fact that electrical power requirements at many isolated locations are very enormous and it does not make economic sense to use stand-alone PV systems. A hybrid system that uses both PV power and genset such that the genset provides the back-up power for the PV, significantly reduce PV power needs and also makes the overall system more reliable (CANMET, 1991). A schematic diagram of a typical PV/genset hybrid system is as shown in figure 2.9.

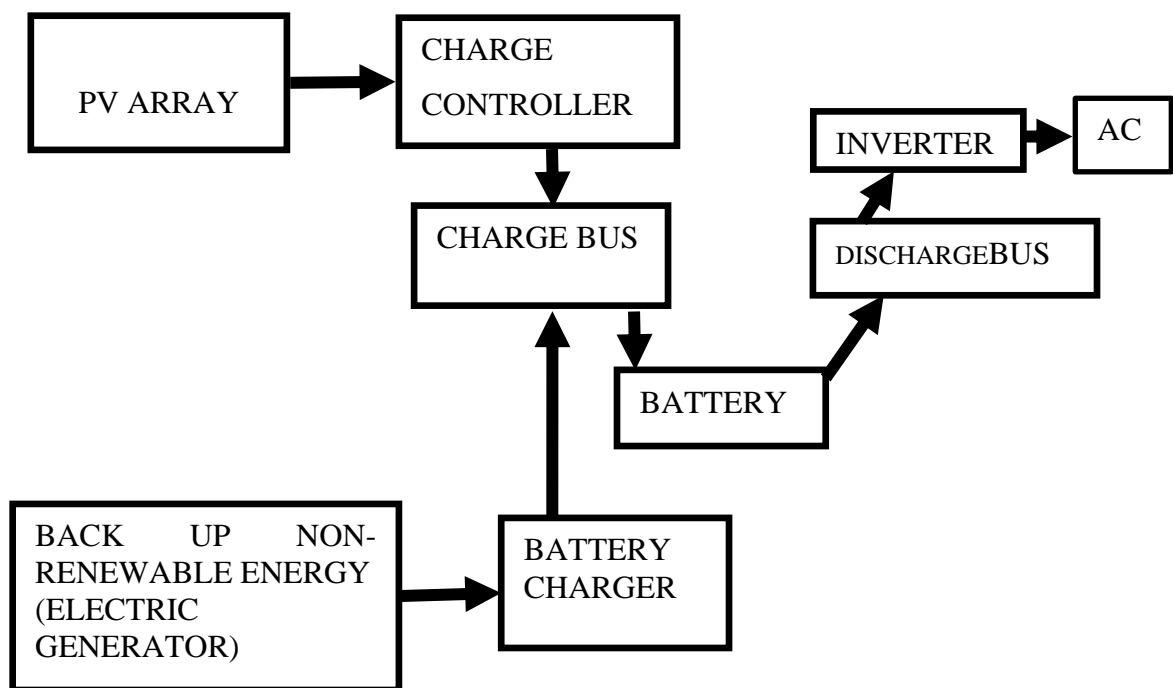


Figure 2.9: Hybrid PV system

2.6.4.3 Grid Connected System

Solar energy has been one of the most active energy and development research areas amongst the diverse renewable-energy sources possible to generate electricity both for grid-connected and off-grid (stand-alone) applications (Gupta and Garg, 2013). A grid connected photovoltaic system is a solar system where the output of the PV panel is connected to feed into the grid supply. There are two major types of grid integrated PV systems namely; grid

connected PV system with, and without battery backup (Dadzie, 2008). Figure 2.10 shows a typical grid connected PV system.

The benefits of a grid-connected system as opposed to a stand-alone system, include saving on wiring costs since the systems use existing wiring in the building, exclusion of storage batteries (system without battery backup) as the grid provides the backup, and the opportunity of selling surplus electricity to the grid. In some cases the peak time for solar energy supply goes well with the peak load on the grid. In a typical installation the PV modules are mounted on a house roof or integrated into the cladding of a commercial or industrial building. The dc electrical energy generated by the PV system is converted to ac power via a power conditioner (Hacker et al., 1993).

Dadzie (2008) points out that within the grid connected PV system using battery backup are mainly the PV array, batteries, inverter, controller (if not included in inverter already) and meter (if required). The integration of grid connected photovoltaic system is analogous to a generator attached to the grid supply. In a grid connected PV system with battery backup, the system works as a standalone power system during grid failure, to do away with the use of a fuel generating plant. Grid connected applications such as electric utility generating facilities and residential rooftop installations make up a smaller but more rapidly increasing segment of PV utilisation.

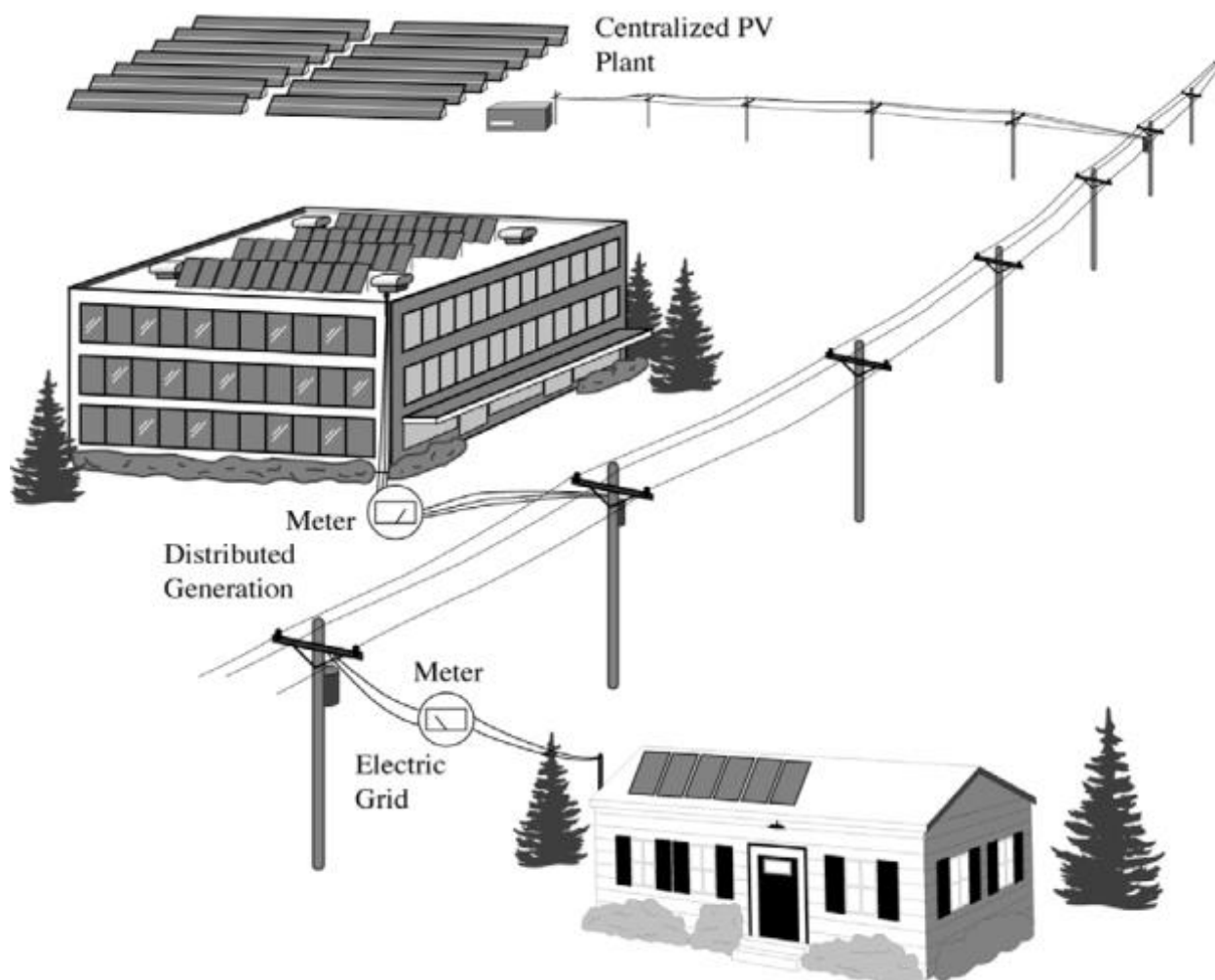


Figure 2.10: A typical grid connected solar PV system Dadzie (2008)

2.6.5 Viability of Solar PV for Water Pumping

Many studies, including those of Barlow et al (1993), EmCon (2006), Meier (2012) and Shrestha et al (2014) have been made to analyse the economic viability of PV pumping. They provide some guide for selecting a power source for rural water supply.

For instance, Meier (2012) reports that an analysis made by some researchers in early 1990s concluded that PV pumping is economically more interesting than diesel generator pumping up to an equivalent volume-head product (hydraulic energy) of 6000 m⁴/day; this value further increased to 8000 m⁴/day by 2005 revealed by another study (Meier, 2012). The report further noted that comparative analysis based on life-cycle cost (LCC) conducted in Kenya around 2010 also showed that PV pumping is significantly cheaper than diesel powered pumping for community sizes between 500 and 1500 people.

Barlow et al (1993) and Shrestha et al (2014) also argue that rural water can be supplied using wind, solar energy (both renewable) or diesel (non-renewable) generator as possible options, and each has its own conditions for economic operation. Shrestha et al (2014) and Barlow et al (1993) note that if the daily volume-head product (daily duty) of water supply is less than 800 m^4 (e.g. $80 \text{ m}^3 \times 10 \text{ m}$) then the following choices will be economically viable: Solar PV will be the best choice for water pumping if the location's monthly average wind speed is less than 2.5 m/s but the minimum daily insolation exceeds 2.5 kWh/m^2 (Shrestha et al, 2014) or exceeds 2.8 kWh/m^2 (Barlow et al, 1993). On the other hand, wind energy will be the best option if the location's monthly average wind speed exceeds 2.5 m/s but the insolation is less than 2.5 kWh/m^2 (Shrestha et al, 2014) or less than 2.8 kWh/m^2 per day (Barlow et al, 1993). Diesel generator will become the most preferred choice only when the conditions for using wind and solar PV are not met (Barlow et al, 1993; Shrestha et al, 2014). Similar argument is made by Meier (2012).

In Ghana for instance, it is reported that wind speed at the coastal areas exceeds 4 m/s but the country's average wind speed is less than 2.5 m/s (actual being about 1.5 m/s ; Akuffo, 1991; Energy Commission, 2009). Thus, wind energy is suited for powering wind turbine mainly at the coastal areas, making the technology location specific. Solar energy on the other hand is all over the country with insolation values ranging between 3.1 and 6.5 kWh/m^2 per day. Since the country's daily minimum insolation (3.1 kWh/m^2) exceeds the threshold (2.5 or 2.8 kWh/m^2) specified by the researchers (as stated above), solar PV becomes the obvious power source selected for rural water supply and hence used in the current research.

The next section discusses some challenges facing the PV and the possible solutions to those challenges.

2.6.6 Challenges and Solutions for using Solar PV

Peltm et al. (2012) note that although the deployment of photovoltaic systems has been increasing steadily since the 1990s, solar technologies still face some economic and technical challenges making the technologies uncompetitive in an energy market controlled by fossil fuels. These challenges include high capital (up-front) cost, modest conversion efficiency and, intermittency- solar energy can vary seasonally and lower output in cloudy weather (Peltm et al., 2012). From a scientific and technical viewpoint, the development of new technologies with higher conversion efficiencies and low production costs is a key

requirement for enabling the deployment of solar energy at a large scale (Global Climate and Energy Project; EPIA, 2011).

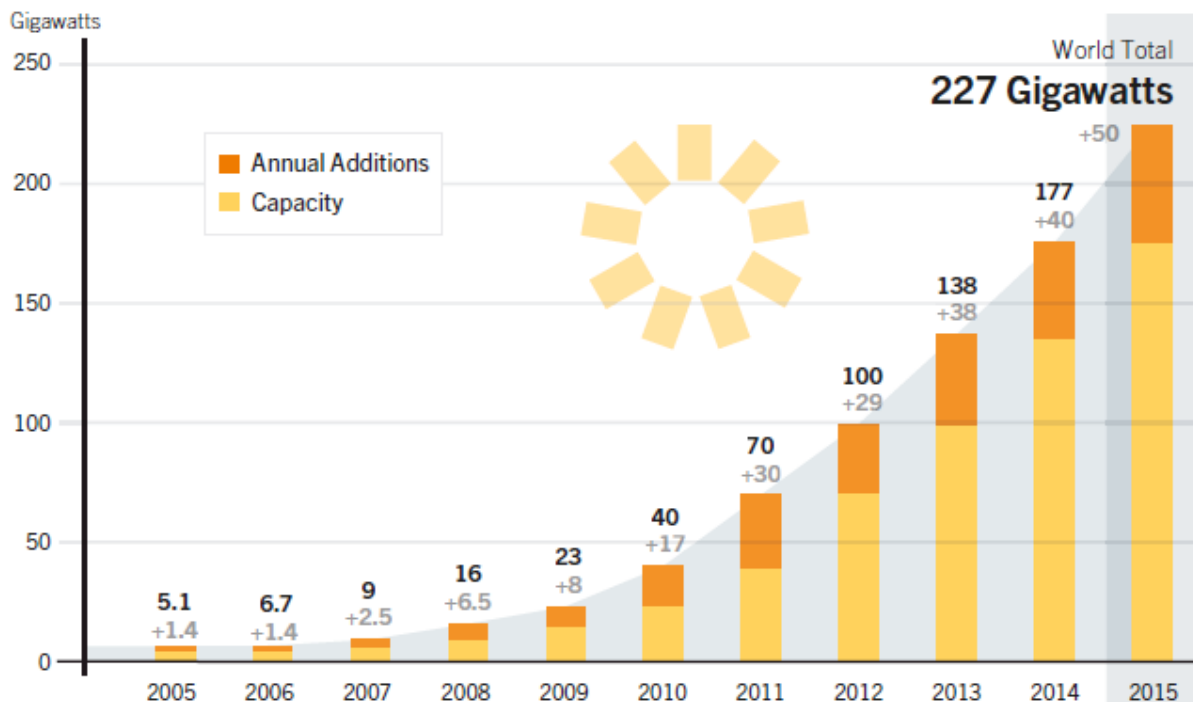


Figure 2.11: Solar PV Global Capacity and Annual Additions, 2005-2015 (REN21, 2016)

In spite of the fact that solar PV technology was expensive, there has been a tremendous reduction in the real price of the modules through an improved cell manufacturing technologies and also because of larger manufacturing volumes (McNelis, 1988; Meah et al., 2008; Reinhard, 2013). It is further noted that research efforts are continuing on a broad front to develop better photovoltaic devices and lower cost systems leading to overall potential cost reduction of the modules (Mc Nelis, 1988; Reinhard, 2013). In support of this view, Meah et al. (2008) argue that while module production increases rapidly, the price of it decreases also almost at the rate it is being produced. World Energy Council (2016) reports that, costs for solar power are falling rapidly resulting in “grid parity” achievement in many countries and new markets for the solar industry are opening in emerging and developing nations. According to the Council, global installed capacity for solar-powered electricity reached around 227 GWe at the end of 2015 (World Energy Council, 2016). Reporting on solar PV market experience between 2005 and 2015 (see figure 2.11), REN21 notes that in 2015 alone, solar PV experienced 25 % annual market growth over the 2014 figure; this brings the total global capacity to approximately 227 GW (REN21, 2016).

Clearly the cost of the module will no longer be a serious issue with this technological advancement being made.

2.7 Solar PV Application for Rural Water Supply

Potable water supply and livestock watering are the commonest uses of solar PV pumps particularly in arid and semi-arid areas which often have very high levels of insolation (solar radiation) year round (AFREPREN/FWD, 2012; Barlow et al, 1993). Solar photovoltaic (PV) for water pumping particularly in a rural setting has a lot of advantages; the first of which is that it is environmentally sound in performance on a life-cycle basis. The solar PV is very clean; it helps mitigate some of the most serious environmental problems including air pollution and climate change. IEE Policy (Anderson et al., 2006).

Technically, solar PV requires low maintenance and can operate for long periods unattended. The modular nature of the solar panel facilitates additional energy generating capacity which makes them a good choice for electricity generation in remote applications. (Anderson et al., 2006; Pelt et al, 2012). Apart from those advantages, Khatib (2010) also notes that the PV pumping system is easy to install, it is reliable and has capability to be matched to demand. He however states its disadvantage is that it has high initial cost and its water production fluctuates.

A study conducted by SELF, (2008) reveals that for small to medium sized wells, a solar PV pump is much cheaper on a life cycle cost basis than diesel-powered (DP) pumps. When this is considered beyond the original purchase price, solar PV pumping systems cost between 22-56 % of what diesel pumps cost and can achieve a payback over it in as little as 2 years (SELF, 2008). This observation agrees with what is reported by Barlow et al (1993).

In the following section, PV water supply system design is discussed.

2.7.1 Solar PV Water Supply System Design

Solar PV water system can be designed manually, or by the use of nomograph and by PV design software such as HOMER. HOMER is an acronym of Hybrid Optimization Modeling of Energy Renewable. Another design-software is the Grundfos WinCAPS (explained in chapter 6). In each case, some initial design parameters need to be specified as discussed below. For this study, the full design and the implementation of the PV water system can be

seen in chapter 6 of the thesis. Manual design of the current system can also be seen in Appendix VII.

For a solar photovoltaic powered water pumping system to perform optimally, there are some initial essential conditions that must be met before considering system design. These initial conditions are: effective system planning, maintenance schedule, sufficient and stable solar irradiance on site and site evaluation (Shrestha, 1996).

When the essential conditions are satisfied, then the following parameters suggested by Morales and Busch (2010) are determined: water requirement, water source, system layout, water storage size, site insolation, the flow rate (discharge) and the total dynamic head. With these parameters determined, the PV panel, pump/motor set and other components are selected; the system is then designed and run to ensure it operates as desired (Morales and Busch (2010)). A summary description of the completed system is given out to user caretakers so as to inform them of the system specifications and requirement. This is said to facilitate and enhance proper care and operation of the system (Morales and Busch, 2010).

2.7.2 Components of Solar PV Water pumping System

A typical solar photovoltaic water pumping system consists of the following main components:

2.7.2.1 Photovoltaic array

Photovoltaic array is a combination of photovoltaic panels (which are made up of modules) connected in series, parallel or both to ensure that the required system voltage is available. When panels are connected in series, the voltages of each individual panel are summed together to get total system voltage but the current of the system is the same as the current of one panel. For parallel connection, the system current is the summation of currents of each panel but the system voltage is the same as the voltage of each panel (Global Sustainable Energy Solutions -GSESPL, 2006; Morales and Busch, 2010; Jha, 2013).

2.7.2.2 Electric Motor

The choice of electric motor for a PV-powered system is dependent on efficiency, price, reliability, the required size, the need for the motor to be submersible or not, and the

availability of driving electronics (for instance power conditioners) which are used to suppress some or all electrical disturbances (Argaw et al, 2003). There are two major categories of motors, DC and AC.

The DC motors are permanent magnet (brushed and brushless) and wound-field types. For the former, a permanent magnet produces the magnetic field in the motor, so no power is consumed in the field windings therefore higher efficiencies are attained. However, for the latter, the field windings produce the magnetic field electromagnetically and hence some amount of power is consumed. For a simple PV system (i. e. smaller PV applications), a DC motor is the best option compares to AC motor as the modules produce direct current and less specialized power conditioning equipment is needed (Barlow et al, 1993; Argaw et al, 2003; Argaw, 2004). This type of motor is suitable for industrial applications (Barlow et al., 1993; Argaw, 2004).

Likewise, an AC motor is either induction (asynchronous) or synchronous type. Induction motors are further divided into squirrel-cage and wound-rotor types. The squirrel-cage induction motor is the simplest and cheapest and its low cost and rugged construction make it the most commonly used motor for wind and PV applications (Barlow, 1993; Argaw, 2004).

Wound-rotor motors are generally used for industrial applications. AC motors in general, are limited to high power applications in PV-powered pumping systems because they require inverters and thus introducing additional costs and some energy loss within the system. They are cheaper and less efficient than DC motors (Barlow et al 1993; Thomas, 1992).

2.7.2.3 Pumps

The most common pump types are the helical rotor pump (progressive cavity), the diaphragm pump, the piston pump and the centrifugal pump. Some examples of pumps under their brand names are: Grundfos SQ Flex, Lorentz PS Series, Total Energie TSP 1000, Total Energie TSP 2000+ and Watermax (EmCon, 2006).

The best type of pump for a particular application depends on the daily water requirement, total head and the water source (Argaw et al, 2003). They explain there are a variety of types of pumps available (i. e. positive displacement and rotor dynamic pumps) that are suitable for

incorporating in a solar PV, so choice of any type must always be reliably tailored to the desired pumping demands.

Barlow et al. (1993) observe that the operational characteristics of reciprocating (positive displacement) pumps are not a good match to the output of PV arrays. The motor driving the pump requires a constant current for a given head, apart from the starting current which tends to be higher. But reciprocating pumps have cyclic (fluctuating) characteristics and exerts cyclic load on the motor. So when coupled to a solar PV array the fluctuating behavior causes variations in the electrical impedance corresponding to the variations in the torque as seen by the PV array (Barlow et al., 1993). As this occurs, the array fluctuates away from its maximum power point (MPP) usually at the starting of the motor-pump set when the torque is high at full system pressure even at low speeds (Argaw et al, 2003; Barlow et al, 1993). The need for electronic power conditioning to smooth out these impedance changes by dynamically matching the current/voltage characteristics of the array with those of the motor becomes crucial. This is discussed in the next two sections.

For centrifugal pumps on the other hand, water output increases with increase in the pump's rotational speed but these pumps are designed for a fixed head. They have an optimum efficiency at a design head and rotational speed therefore any deviation from this design point decreases its efficiency. Centrifugal pumps nevertheless, offer the possibility of achieving a close natural match with a PV array over a wide range of operating conditions. The reason is that centrifugal pumps are not cyclic as pertains in the reciprocating pumps, and so they do not experience the type of matching problems associated with reciprocating pumps (Barlow et al., 1993). Centrifugal pumps are more reliably used as submerged motor-pump sets and suited for heads ranging between 10 – 30 m (Argaw, 2004). The reason for this is that these pumps are not inherently self-priming, and can easily lose their prime at higher suction heads.

Argaw et al (2003) and Argaw (2004) state that, generally reciprocating pumps are best for low flows (under 15 m³/day) and high pumping heads (30–150 m) whereas submersible centrifugal pumps are best suited for high flow rates (25–100 m³/day). It is important that pump requirements are specified precisely when designing and selecting a pump for application. Figure 2.12 is a schematic diagram illustrating a solar PV water pumping system using a submersible motor-pump set. However, the diagram does not include a water level detector down the borehole.

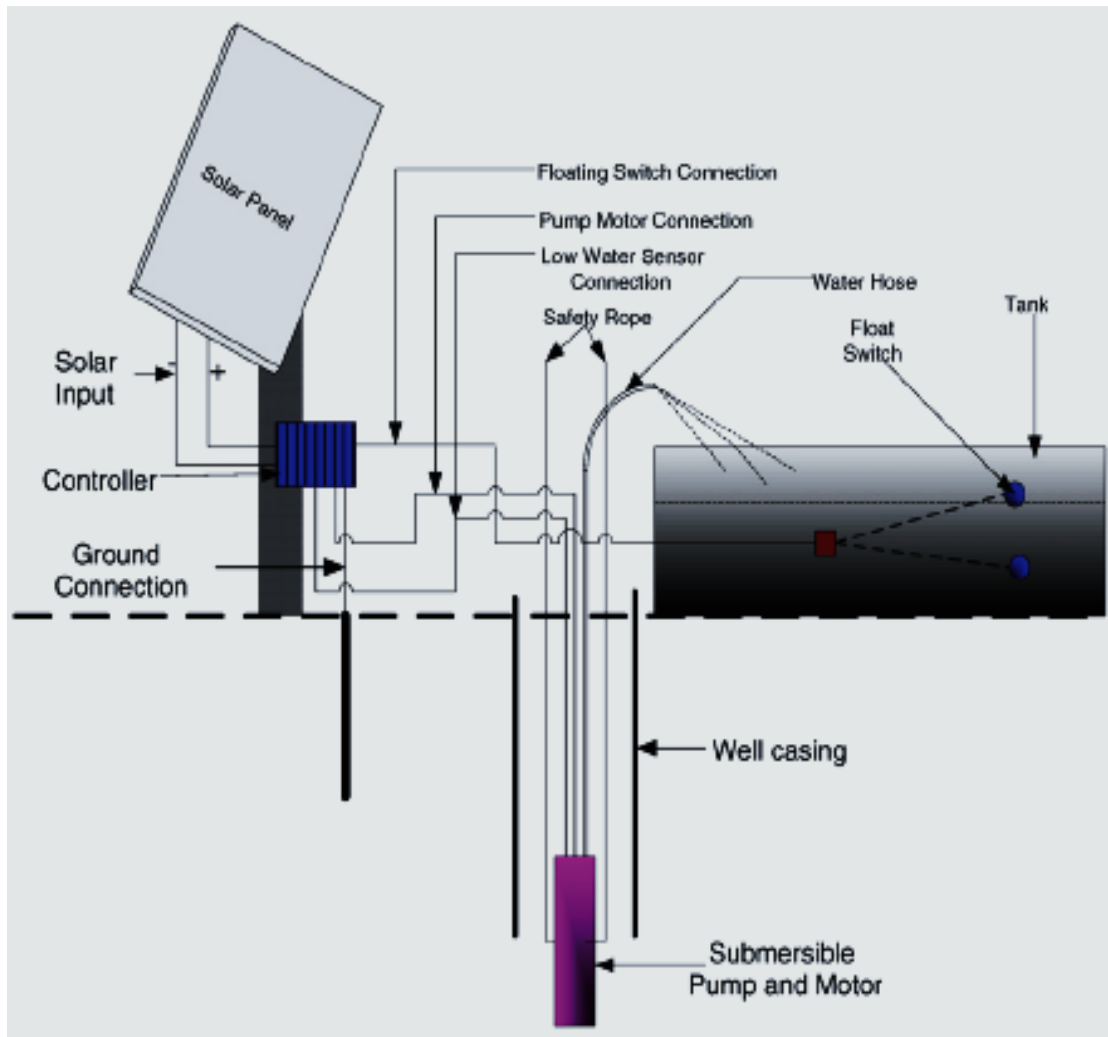


Figure 2.11: Schematic diagram of solar PV pumping system (Pelt et al. (2012)).

2.7.2.4 Controller

A controller is any electronic device which matches the PV power to the motor and regulates the operation of the PV pump. It is mostly installed on the surface but some solar PV pumps have the controller integrated in the submersible motor-pump set. In the next section the process of power conditioning in the PV system is discussed.

2.7.3 Power Conditioning in Solar PV Pumping

It is important to use some form of power conditioning equipment (controller) in the PV system to obtain a good match between the PV array and electric motor characteristics

(voltage and current). The controller modifies the power coming from the array to make it more compatible with the current - voltage requirements of the motor. Equipment used for power conditioning purposes may be impedance matching devices, batteries, DC to AC inverters, switches, protective cut-outs and many more.

The electrical characteristics of the motor and the array are matched by employing impedance matching devices to enable both the motor and the array function close to their maximum efficiency over a range of conditions and sunlight levels. Maximum power point trackers (MPPTs) are examples of impedance matching devices. They are 'intelligent' devices usually employing a microprocessor that allow the array to operate at its peak power point (Dzokoto, 2000; Barlow et al., 1993). The matching can also be achieved by fixing the PV array voltage constant, in this manner, the array will then operate close to its maximum efficiency over a wide range of irradiance levels.

Batteries also offer a means of impedance matching. However, they are less attractive because of self-discharge (efficiency as low as 70%), and they require regular maintenance.

Inverters which convert DC to AC are used to enable PV arrays to drive ac motors. Although their efficiencies can be as high as 97 %, they are expensive and so should not be used on small PV systems where their additional cost may not compensate for the reduced cost of an AC motor (Barlow et al., 1993; Dzokoto, 2000).

Switches and cut-outs protect parts against power surges caused by failure of components or incorrect connection. A motor may over-speed and burn out when a pump runs dry, so it is essential to install water level detector or over-speed cut-out device on remote borehole systems.

2.7.4 Water storage versus Energy storage in Battery

Usually, PV systems rely on battery bank for energy storage to power solar home systems and other appliances at night and in cloudy weather when the solar radiation is absent or fluctuates erratically. However, PV water pumping systems, apart from irrigation purposes, do not necessarily need to use batteries due to battery frequent discharge. EmCon (2006) reports that it is more economical to store water in a reservoir than energy in a battery bank. This observation is in tandem with SELF's (2008) assertion that when water is stored in reservoir and batteries are eliminated from the system, about 1/3 of the system cost and most

of the maintenance is eliminated (SELF, 2008; EmCon, 2006). The observations made by Thomas (1992), Barlow et al. (1993) and (Khatib, 2010) also support the need to store water in a reservoir to cater for two or three days' demand.

The only condition for which batteries may be considered in the PV system despite the weakness, according to Khatib (2010), is if the capacity of the water source is inadequate. In that case by including the batteries into the pumping system, the pumping time can be distributed over a longer period. This can also be done when the pumping time is to be controlled for pumping to be done in a short time but with high flow rate (Khatib, 2010).

Thomas (1992) highlights that two to three days of water storage is usually available at the root zone of plants since evapotranspiration of plants is proportional to solar intensity and so water storage for irrigation purposes may not be necessary.

2.7.5 Block Diagram of Solar PV Pumping System

The block diagram presented in figure 2.13 (adapted from Gouws and Lukhwareni, 2012) summarizes in pictorial form, all the factors considered in sections 2.6 and 2.7 relating to the solar energy resource, the PV and the components constituting the Balance of System (BOS) that influence the system's performance and efficiency. For example, the environmental conditions that influence the system are the solar radiation (clear weather, overcast or cloudy weather), meteorological data especially the site's solar insolation expressed in kWh/m²-day, and Air Mass (AM). Honsberg and Bowden (2017) point out that Air Mass quantifies the reduction in solar power when radiation passes through the atmosphere and is absorbed by air and dust. They state that AM is the path length which sun light takes through the atmosphere normalized to the shortest possible path length (i. e. when the sun is directly overhead). The

Air Mass is defined as: $AM = \frac{1}{\cos\theta}$

where θ is the angle from the vertical (zenith angle). When the sun is directly overhead, the Air Mass is 1. It is universal that in characterising terrestrial power-generating panels, the air mass AM is 1.5, represented as "AM1.5" usually written at the back of a PV panel.

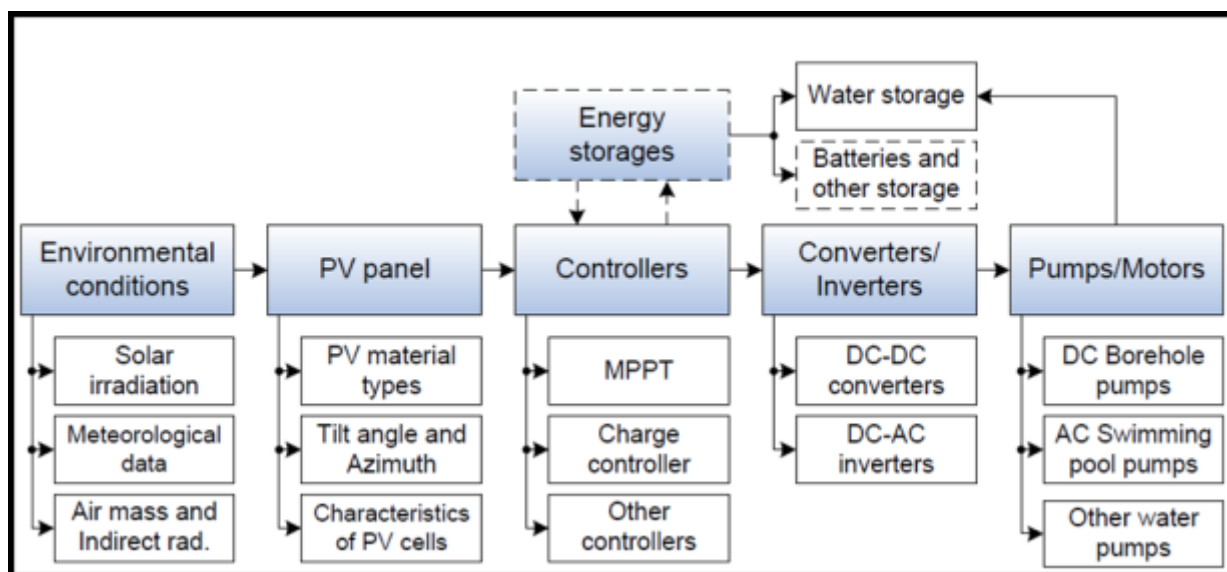


Figure 2.12: A schematic block diagram of solar PV pumping system *Gouws and Lukhwareni (2012)*

For the PV panel, the influencing factors are PV material types, tilt and azimuth angles and PV cell characteristics; while for the controller the maximum power point tracker, charge controller and other controllers may influence the system. Converters (DC-DC) and inverters (DC-AC) may affect the system. The pump type will influence the performance of the system, hence proper selection of system components is imperative for excellent performance and higher efficiency.

2.8 Energy Access in Ghana

This section considers energy access in Ghana. It discusses both conventional and renewable energy access with much focus on solar energy utilization in the country.

2.8.1 Overview of Ghana's Energy Situation

Ghana currently generates about 64 % of its electrical power from hydro sources; electricity being the dominant form of modern energy used in the country accounts for about 65 % of the energy used in the industrial and service sectors and about 36 % in residential (Eshun and Amoako-Tuffour, 2016). Eshun and Amoako-Tuffour report that the country's year-on-year power demand grows by 10 to 15 % with supply generally not meeting target. They note that, apart from the overall population growth of about 2.3 % per annum, the drivers of increasing

electricity demand are expanding industrial and service sectors, growth of the middle class, and growing incomes (Eshun and Amoako-Tuffour, 2016).

Historically, the government of Ghana established its first public electricity company, the Volta River Authority in 1961 for the execution of an energy project initiated for the generation and transmission of power. Between 1965 and 1972, six hydroelectric generating units with a total capacity of 912 MW were installed at Akosombo. In 1981, a second hydroelectric plant of 160 MW was installed at Kpong to bring the total installed capacity of hydropower alone to 1072 MW (Kemausour et al., 2011). By 1990, the grand total electricity generating capacity rose to 1,102 MW when the Tema diesel generating power of 30 MW was added to the existing capacity (Abakah, 1993; Kemausour et al., 2011).

Since then, there have been series of energy policies and interventions over the years in attempt to accessing energy in the country. In 1989, the first phase, the National Electrification Scheme (NES) was rolled out in the hope that within 30 years period the whole nation would be electrified. The goal of the NES is thus, to achieve universal access of reliable electricity supply to all communities over a 30-year period, 1990-2020 (Abavana, 2010; Barfour, 2013; Akuffo, 2007). All communities with a population above 500 were connected to the national grid at the beginning of the scheme (Abavana, 2010; Akuffo, 2007; Kemausour et al., 2012).

As part of the strategies, National Electrification Programme (NEP) and Self Help Electrification Programme (SHEP) were initiated. All the district capitals including towns and villages on the way to the district capitals were connected to the grid. Access to electricity was 28 %. The SHEP was the government's complementary programme to accelerate the electrification process by electrifying towns and villages which were 20 km away from the grid and prepared to help themselves. i. e. towns and villages that were ready to contribute to the cost of electrification of their communities. Access to electricity then rose from 28 % to 54 % by 2005 (Barfour, 2013; Akuffo, 2007).

In similar studies, Kemausour et al., (2011) and Bhattacharyya (2013) also report an increasing trend in electricity access in Ghana between 1988 (28 %) and 2008 (55 %). In 2009, the electricity access was 60 % (Bhattacharyya, 2013). Bawakyillenuo and Agbelie (2013) citing the Energy Commission of Ghana also note that the access figures stand at 28 %

in 1988, 43.7 % in 2000 and about 66 % in 2010. They observe however that, while household access in urban areas is 81 % rural households' access is 24.9 % (Bawakyillenuo and Agbelie, 2014).

In spite of the increasing trend in electricity access, there has been a great disparity between the urban and the rural coverage as reported by Bawakyillenuo and Agbelie (2014). This observation supports Bhattacharyya's (2013) assessment on Ghana's energy trend from 1988 to 2009, he states that: "*the richest rural households have electricity access similar to that of the poorest urban households*" (Bhattacharyya, 2013: 134).

Ghana's rates of access to electricity as of 2014 is estimated at around 72 % with over 87 % in urban areas and a little under 50 % in rural areas; local demand is growing at about 10 % annually, this requiring extra growth in energy generation (IRENA, 2015). Consumption per capita stands at 443.3 kWh (2012 latest figure) (Barfour, 2013).

2.8.1.1 Ghana's Energy Plan

The Strategic National Energy Plan 2006-2020 (SNEP) is a document prepared by the Energy Commission which serves as a guide to the development of the energy sector in the country for the period 2006 -2020. (Energy Commission-Ghana, 2006; Kemausour et al., 2011). The country is confronted with major challenges in providing the required energy in a reliable and sustainable manner in the face of an expanding economy and a growing population. Among the challenges are: operational inefficiencies of the utilities leading to high losses and thus increasing cost of supply and distribution; over reliance on wood-fuels, with its attendant threat to the country's forest cover; solar energy, which is relatively abundant, is barely exploited to supplement the commercial energy requirements of the country and inadequate investments to match the growing demand due to lack of capital (Energy Commission, 2006; p24; Atsu et al. 2016)

The government set a target of achieving 5,000 MW installed generation capacity by 2016 from a total installed capacity of 2170 MW as of 2011 (Energy Commission, 2011). Meanwhile, Atsu et al. (2016) report that as of April 2013, Ghana's installed power generation capacity is 2480 MW but total dependable capacity is 2267 MW out of which 1200 MW is hydro power, 1065 MW from thermal and 2 MW being solar power (Atsu et al., 2016).

Ing. Julius Kpekpena of Electricity Company of Ghana in a private telephone interview also reports that as of 2014, total installed capacity stood at 2,800 MW but due to some technical challenges, the actual operating capacity is 2,631 MW (Kpekpena, 2015). The breakdown is as follows: 1382 MW from the three hydro power sources; 1245 MW from thermal power sources; 2.1 MW renewable energy and 1.9 MW from Independent Private Power Producers.

Between 2011 and 2015, Ghana's power penetration trend has been irregular due to poor rainfall conditions and the West African Gas Pipeline (through which Ghana receives gas supply from Nigeria) disaster preventing gas supplies to the country's thermal power plants. From the beginning of 2011, the country has to undertake electrical load shedding, as such, increase in power generation cannot keep pace with increased demand for power (Energy Commission, 2011). The Commission states that despite the shortfall, Ghana continues to export electricity to her neighbouring countries Togo, Benin and Burkina Faso. Consequently, the load shedding exercise lasted almost four years in the whole country which adversely affects small towns, peri-urban and rural communities and small industries in particular.

To foster economic growth as well as improve quality of life of its populace, the Government of Ghana (GoG) recognizes the need to diversify the national energy mix to take account of renewables such as hydro, wind, solar, biomass etc. The policy aims at energy diversification and at increasing the share of renewable energy component from 1 % (mainly solar and biomass) to 10 % of the national energy mix by 2020 (Atsu et al., 2016; Energy Commission, 2010). Therefore the development of the renewable energy resource of the country has become the Government's key policy objective.

2.8.2 Renewable Energy in Ghana

Energy Commission (2011) reports that Ghana is well endowed with renewable energy resources particularly biomass, solar, wind energy resources, and to a limited extent, mini-hydro. The development and use of renewable and energy resources have the potential to ensure Ghana's energy security and also mitigate the negative climate change impact of energy production and use, as well as solve urban and peri-urban sanitation problems. The enactment of the Renewable Energy Act 832 in November, 2011 for the promotion of renewable energy development, management, utilisation, sustainability and adequate supply for generation of heat and power in Ghana is a major intervention to address the challenges

facing the energy sector and climate change effects (Energy Commission, 2011). The Act provides the framework for Government support for electricity generation and supply of electricity from renewable energy sources as well as create the enabling environment to attract investment into renewable energy sub-sector. It aims at encouraging businesses, households and communities to adopt renewable energy technologies and also increase their use in the energy mix. It is expected that the use of RE will help to diversify electricity supply sources and thereby safeguard energy security. It will also improve access to electricity for all categories of users and lead to building indigenous capacity in technology for renewable energy sources. The components of the Act include the feed-in-tariff scheme, the renewable energy purchase obligations, establishment of an energy fund and it is to provide incentives as strategies to promote Renewable Energy Technologies (Atsu et al., 2016).

Renewable energy is one of the sources for rural electrification in the country. Barfour (2013) points out that, various aspects of management and implementation of the rural electrification component have been vested in the Ministry of Energy, local consultants, engineers, foreign and local contractors and beneficiary agencies which are the distribution utilities (Barfour, 2013).

Financing of the rural electrification is however, public private partnership arrangement, multilateral and bilateral sources from development partners. The public sector would also be used through budget and concessionary loan facilities for special infrastructural programmes. National electrification levy from customers and internally generated funds from power sector companies would also be components of the financing strategy to be used (Barfour, 2013; Mahu, 2015).

2.8.2.1 Biomass

Ghana has a total stock of direct wood fuels of about 832 million tonnes. These are made up of timber logging, sawmill and ply-mill residue and other reserves of biomass (SE4All Action Plan, 2012). Biomass is the predominant energy consumption in Ghana mainly fuel-wood (firewood) and charcoal, forming over 60 per cent of the total energy consumption. It has been estimated that more than 65 per cent of the people engaged in the wood fuel business are women (Energy Commission, 2006).

2.8.2.2 Biogas

Biogas on the other hand is scarcely tapped as a source of energy. Despite that, biogas from organic and municipal (solid and liquid) waste is gaining popularity in Ghana. There are a number of establishments in Ghana that have installed biogas digesters for exploiting biogas for use domestically and institutionally (Energy Commission, 2006).

2.8.2.3 Hydro

Ghana has three large hydroelectric plants at Akosombo, Kpong and Buipe. The first two plants are on the Volta River; the third, Bui hydroelectric plant is on the Black Volta all with a total installed generation capacity of 1,580 MW (SE4All, 2012). It has also been reported that there are 22 exploitable mini-hydro sites in the country with total potential power between 5.6 MW – 24.5 MW. Continuous decrease of the water level makes the full operation of the hydroelectric plants difficult.

2.8.2.4 Wind

Ghana has about 2,000 MW of raw potential for wind energy. It is currently reliably projected that over 300 MW installed capacity of wind farm could be established at the coastal part to generate over 500 GWh to supplement the nation's energy supply (SE4All, 2012). The Energy Commission reports that with the support from Ghana Energy Development and Access Project (GEDAP) it has conducted Wind Energy Resource Assessments at five selected sites in Ghana (EC, 2012). The Volta River Authority has erected and commissioned a 100 MW Wind Power Plant at Kpone, near Tema in 2015 as was projected by Solar Energy for All.

The Energy Commission (2009) reports that data on the annual average wind speed ranges from 2.9 to 5.5 m/s at 12 metres high, whereas speeds extrapolated at 50 metres high (using WASP) range from 3.4 to 7.4 m/s on some locations which are along the coastal belt of the country. Although wind speed in Ghana averages 3 m/s along the eastern coastline, the national average wind speed is 1.4 m/s (Energy Commission, 2009). This shows the use of wind turbine is location specific and a better place in Ghana is along the coastline of the country. Pelt et al. (2012) report that a wind speed of at least 10 mph (4.4 m/s) is necessary for wind turbine to power water pumping system; AFREPREN/FWD gives minimum wind speed

of 3 m/s for the same purpose (AFREPREN/FWD, 2011). It is therefore not practicable to use a wind turbine as a renewable energy technology for water pumping in most locations of the country and this limits the use of wind energy compared to solar PV.

2.8.2.5 Solar Energy

In Ghana, sunshine is available all year round. For over 50 years, the Ghana Meteorological Agency has been collecting solar radiation and sunshine duration data for the country. Other centres like the universities also collect those data; in particular is the Mechanical Engineering Department of the Kwame Nkrumah University of Science and Technology (KNUST). Atsu et al. (2016) report that the daily average sunshine duration for the country ranges from a minimum of 5.3 h in the cloudy semi-deciduous forest regions to a maximum of 7.7 h in the dry savannah regions; the monthly average solar insolation ranges between 4.4 and 5.6 kWh/m²-day. Energy Commission of Ghana reports an average solar radiation of about 4-6 kWh/m²-day and sunshine duration from 5 hours to 8 hours per day (Energy Commission of Ghana, 2009). Table 2.5 shows data on solar radiation of the country.

Table 2.5: Annual Monthly Averages of Solar Radiation (kWh/m²-day) at 19 Synoptic Stations (1993- 2002)

MONTH	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	AV.
KUMASI	4.8	5.3	5.3	5.4	4.7	4.0	4.0	3.8	4.0	4.7	5.0	4.6	4.6
ACCRA	4.7	5.2	5.3	5.7	5.4	4.6	4.2	4.5	5.1	5.6	5.5	4.9	5.1
AXIM	4.9	5.4	5.6	5.6	5.1	3.9	4.2	4.2	4.4	5.2	5.5	5.0	4.9
NAVRONGO	5.4	5.4	5.8	6.0	5.9	5.7	5.3	5.1	5.3	5.7	5.6	4.8	5.5
SALTPOND	4.9	5.6	5.5	5.7	5.4	4.4	4.7	4.5	5.0	5.7	5.7	5.2	5.2
ADA	5.0	5.4	5.6	5.9	5.6	5.0	5.1	5.1	5.5	5.9	5.5	5.4	5.4
KOFORIDUA	4.7	5.1	5.3	5.4	5.3	4.6	4.1	3.8	4.4	5.2	5.2	4.9	4.8
WENCHI	5.2	5.5	5.5	5.7	5.5	5.0	4.4	4.1	4.4	4.9	5.1	4.9	5.0
TAMALE	5.1	5.5	5.6	5.9	5.9	5.5	5.0	4.8	5.0	5.5	5.7	5.2	5.4
BEKWAI	4.7	5.1	5.3	5.5	5.3	4.6	4.1	3.8	4.1	5.0	5.0	4.4	4.7
HO**	4.9	5.2	5.5	5.7	5.6	4.9	4.6	4.2	4.7	5.5	5.6	5.1	5.1
WA	5.5	5.8	5.8	5.9	5.9	5.6	5.1	4.9	5.1	5.6	5.6	5.4	5.5
AKIM ODA	4.5	4.8	4.9	5.2	4.9	4.3	4.0	3.8	4.2	4.8	4.9	4.5	4.6
KRACHI	5.1	5.4	5.7	6.0	5.9	5.2	4.7	4.5	4.8	5.3	5.7	5.1	5.3
YENDI	5.2	5.5	5.6	5.9	5.9	5.4	5.0	4.6	5.0	5.6	5.7	5.2	5.4
TAKORADI	4.8	5.4	5.5	5.7	5.2	4.4	4.4	4.2	4.6	5.5	5.6	5.0	5.0
BOLE	5.4	5.8	5.8	5.8	5.7	5.1	4.6	4.5	4.8	5.5	5.5	5.3	5.3
ABETIFI	5.0	5.5	5.6	5.6	5.4	4.8	4.8	4.6	4.7	5.2	5.6	5.1	5.2
AKUSE	4.6	5.1	5.2	5.0	5.3	4.6	4.3	4.1	4.7	5.3	4.8	4.8	4.8
Average	5.0	5.4	5.5	5.6	5.5	4.8	4.6	4.4	4.7	5.4	5.4	5.0	5.1

Energy Commission (2014) ** Measured data for Ho (closest station to case study area)

There are three climatic zones with solar insolation values in the country (Energy Commission, 2009; Frimpong, 2013):

- i. Savannah zone (closed to the Sahel) from 4.0 kW/m²-day to 6.5 kW/m²-day
- ii. Middle Forest zone from 3.1 kW/m²-day to 5.8 kW/m²-day
- iii. Savannah (Coastal belt) from 4.0 to 6.0 kW/m²-day

The Energy Commission notes in its 2011 Annual Reports that it has initiated a “Grid Connected Wind and Solar PV Electricity Supply System Pilot Project” as phase I of the project in November 2009. The first phase of the project was completed in 2010 and involved the installation of 25kW of grid connected solar PV systems in the Greater Accra Region. The phase I project was a public-private partnership arrangement where funds from the Energy Fund were used to leverage both individual and institutional investments in financing grid-connected solar PV and wind projects (Energy Commission, 2012). About 30% of the total hardware cost which amounted to about sixty thousand Ghana Cedis (GH¢ 60,000.00; equivalent to about £20,000.00) was contributed by the Commission.

A typical installation can be seen in figure 2.14 by courtesy of Energy Commission.

Furthermore, reversible meters were pioneered to enable a study of the modalities for full scale implementation of Feed-In-Tariffs as part of preparations towards the implementation of the Renewable Energy Act. It has also been stated that in 2011, eighteen solar PV systems with a total capacity of 177kWp were installed at various locations in Ghana. Out of this total, 68.44kWp of solar PV systems were installed at six locations, indicated in table 2.6.



Figure 2.13: A typical grid connected solar PV EC, 2011

Table 2.6: List of Completed Solar PV Installations

S/No	Beneficiaries	Location	Capacities
1	Wienco Gh Ltd	Atimpoku, Eastern Region	42.77 kW
2	Trade Works Company Ltd	South Dome, Ga East District, GAR	10.58 kW
3	Residence I	Tema, Greater Accra Region	4.00 kW
4	Residence II	Tema, Greater Accra Region	4.00 kW
5	Residence III	Peduase, Eastern Region	3.80 kW
6	Residence IV	Tesijriganor, Ga East District,	3.29 kW
Total			68.44 kW

Energy Commission, 2011

Table 2.7: Solar PV installations in Ghana

SOLAR PV SYSTEMS	INSTALLED CAPACITY (MW)	GENERATION (GWh)
Rural home system	450	0.70 – 0.90
Urban home system	20	0.05 – 0.06
School system	15	0.01 – 0.02
System for lighting health centres	6	0.01 -0.10
Vaccine refrigeration	42	0.08 – 0.09
Water pumping	120	0.24 – 0.25
Telecommunication	100	0.10 – 0.20
Battery charging system	10	0.01 – 0.02
Grid connected system	60	0.10 – 0.12
Solar streetlights	10	0.04 – 0.06
TOTAL	853	1.34 – 1.82

Energy Commission-Ghana, 2009 REEP

Table 2.7 shows some solar PV systems installed all over the country. Data collected from the field on solar PV installation in Ghana indicate that the private sector is poised to make significant inroads in supply and installation of solar PV systems all over the country.

In the next section, a review of literature on Ghana's potable water access has been made.

2.9.1 Overview of Ghana's Safe Water Access

Water supply in Ghana dates back to 1928 and passed through various developmental stages. From 1965 and until the early 1990s, the then Ghana Water and Sewerage Corporation (GWSC) had been responsible for urban and rural water supply. Within this period, rural water supply coverage was very low. This led to the creation of the Rural Water Department within the GWSC in 1986 to give more attention to the provision of water and sanitation for rural people (CWSA, 2012; ISODEC, 2012). However, the facilities provided were given little or no maintenance and so their use could not be sustained. This is because the beneficiary communities were not paying realistic tariffs that would enable the centralised maintenance unit of the Corporation to maintain the facilities. Engel et al., (2005) argue that failure of the then Ghana Water and Sewerage Corporation to fulfil its mandate made the government introduce various reforms based on decentralization policy, into the water sector.

Before the reforms were introduced in 1994, the central government and external support agencies who were development partners had been responsible for planning, constructing and maintaining rural water supply issues in Ghana. This allowed for only little participation of the private sector, apart from the foreign consulting firms engaged to run projects, and international contractors to drill boreholes (Fielmua, 2011). This system was also not sustainable and therefore called for reforms that involve the communities in the process of acquisition and management of the water facilities.

The government's reforms were to keep pace with the changing conditions in the country and the international scene following the United Nations General Assembly's declaration of 1981-1990 as a decade of International Drinking Water and Sanitation throughout the world (Brima and Fielmua (2011). In 1994, the National Community Water and Sanitation Programme (NCWSP) was launched in line with Government's decentralisation policy (CWSA, 2012; Engel et al, 2005). The NCWSP is to enable the government to focus on reducing poverty in rural areas and to address the problems of water and sanitation in rural communities and small towns.

The fundamental principle of the NCWSP is the emphasis on community ownership and management (COM), which involves community participation in the planning,

implementation and management of the water and sanitation facilities (MWRWH, 2007; Braimah and Fielmua, 2011). In describing what it means by “ownership”, Short and Thompson (2003) citing Bannister (2000) state that “ownership” defines “*a sense of ownership rather than defining the actual possession of the borehole/pumping system*”. The NCWSP is in the belief that rural communities and small towns as custodians will ensure the sustainability of the facilities. Other key issues within the NCWSP are participation of private sector (partner organisations, small business development units, area mechanics and spare parts suppliers); involvement of women in decision making at all levels including their inclusion in water and sanitation management teams (WSMTs). Women are supposed to make up 30 per cent of the teams; they are also supposed to occupy the treasurer’s position. They are trained as pump caretakers who do minor repair and maintenance work on the facilities. The role of women in decision-making for sustainable management of improved water supply in rural areas has been described to be critical by Boateng and Kendie (2015) and Adow (2013). Boateng and Kendie (2015) argue that when women are given the opportunity to express their views on matters that affect their daily livelihood or when they are involved at all levels of water management and policy formulation, they can help to harness the potential of water for development and make sure that water does not become a limitation to sustainable development (Boateng and Kendie, 2015).

As part of the NCWSP the Community Water and Sanitation Agency (CWSA) was launched in 1998 by an Act of Parliament - Act 564. The CWSA is a State Owned Enterprise (SOE) that has been mandated by the Act 564 to facilitate the provision of sustainable potable water and related sanitation services as well as hygiene promotion to rural communities and small towns using the decentralized structures at the district and community levels (CWSA 2012; CWSA, 2013). Specifically, the objective of the Act 564 assigns the following functions to the Agency among others, to:

- i) *Provide technical support to District Assemblies (DAs) in the delivery of safe Water, improved Sanitation and Hygiene (WASH) services to beneficiary communities;*
- ii) *Encourage private sector participation in WASH service delivery;*
- iii) *Assist and coordinate Non-Governmental Organisations (NGOs) in the Community Water and Sanitation sub-sector;*
- iv) *Perform any other functions assigned to it by the Act. (CWSA, 2013: 5-6)*

Although the management of the NCWS programme is by CWSA through its 10 regional offices, the actual implementation is done by the district assemblies (DAs). Each district assembly has a District Water and Sanitation Team (DWST) responsible for the implementation of the programme. Figure 2.15 indicates functional hierarchy of National Community Water and Sanitation Agency in the implementation of its community water and sanitation programme.

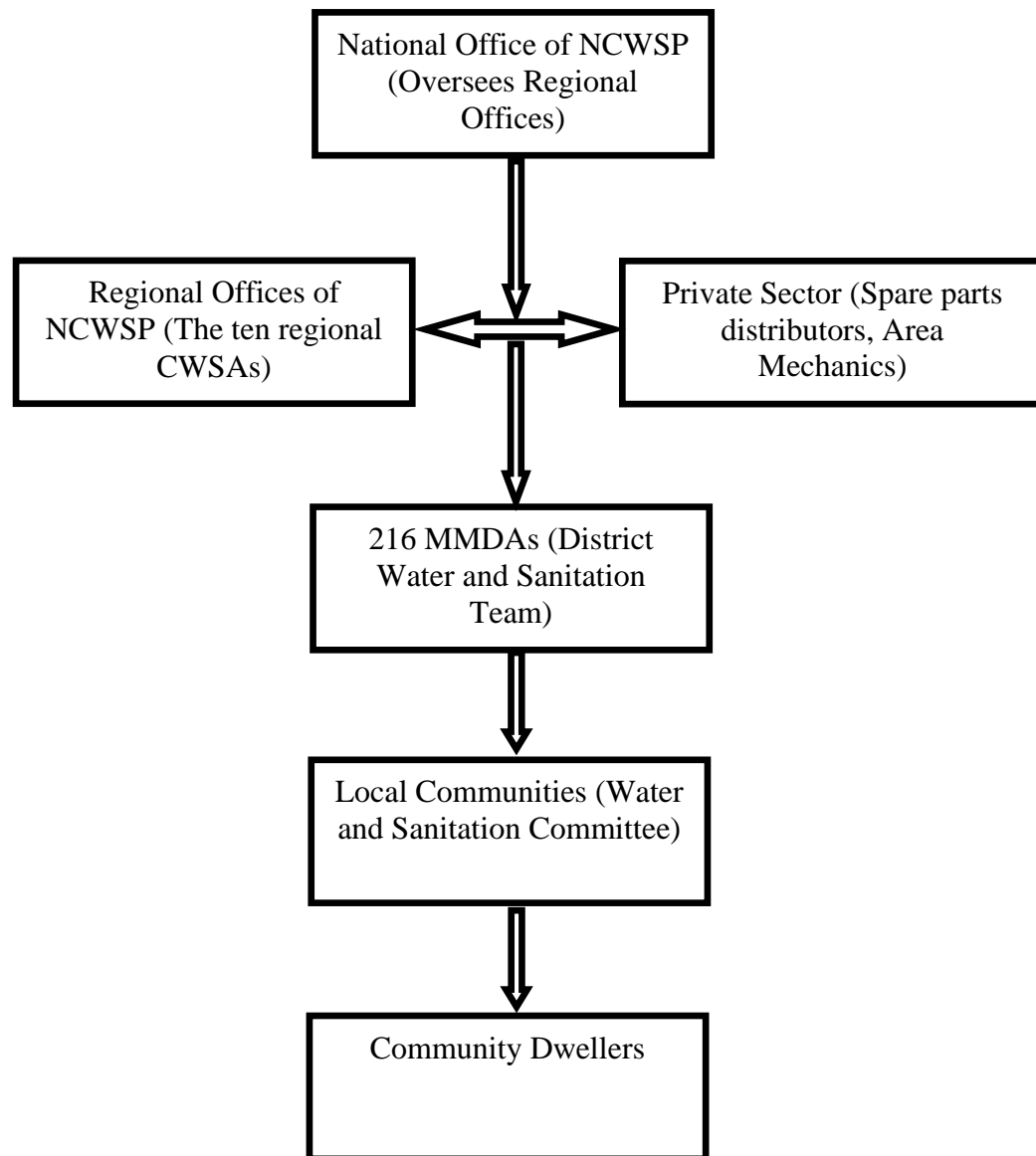


Figure 2.14: Functional hierarchies of NCWSP Implementers

2.9.2 Financing

Basically, the financing of projects is done by the Government and her Development Partners (DPs). However, cost sharing arrangement between the DPs and beneficiaries of the project is as follows: 90 % of the total cost of community water and sanitation facility is borne by

external development partners; 5 % by the government of Ghana through the district assembly of the beneficiary community and 5 % is contributed by the beneficiary community in cash or kind or both. This 5 per cent contribution is for the community to show how ready and committed it is in owning the facility (MWRWH, 2010; ISODEC, 2011). In 2009 however, the Government of Ghana abolished the 5 % community share and increased the district assembly's share to 10 % (WSP, 2011; Eyrarnh, 2013).

2.9.3 Technology

There are basically two main types of water supply and sanitation options provided. Each of these has various options as shown below:

The first is small communities (population up to 2000 people) with point sources including; hand dug well fitted with hand pump, spring source, borehole fitted with hand pump, mechanized borehole with limited distribution and rain water harvesting. The second is small towns (population above 2000) with piped schemes including: ground water based piped scheme, spring or highland gravity water supply schemes, surface water with slow sand filtration piped schemes, surface water with minimal conventional treatment schemes and other technologies based on prevailing conditions

Water source selection is prioritised as follows: ground water including springs; relatively unpolluted surface water; and slightly polluted surface water.

2.9.4 Facility Construction, Operation and Maintenance

While construction of rural water supply systems and other physical facilities is handled by private companies and artisans as stipulated in the Act 564, there are support structures that facilitate Operation and Maintenance (O & M) of completed facilities. Support is provided to districts and communities for operation and maintenance to enable them implement their Facilities Management Plans (FMPs). The FMP is a well-documented guideline drawn to guide the operation and also specify job description of the water and sanitation management team. The Operation and Maintenance of point sources are carried out by Water and Sanitation Management Teams (WSMTs) of small communities. This team is made up of elected members of the communities to implement the FMPs; it is supported by pump caretakers and area mechanics. In addition, there is a National Spare Parts Distribution

Network zoned in the southern, central and northern parts of the country to supply spare parts for effective O & M purposes (CWSA, 2011 and CWSA, 2012)

The components or the requirements of operation and maintenance concept can be illustrated as a triangle seen in figure 2.16. The beneficiaries (i. e. the community) are situated at the top and at one corner is the District Water and Sanitation Team (DWST) who provides facilitation and at the opposite corner is the private sector (i. e. partner organisations, small business development units, area mechanics and spare parts suppliers) that provides the service. Similarly, the operation and maintenance (O&M) for piped schemes are carried out through the employed staff of Water and Sanitation Development Boards (WSDBs) and also through contracts with Private Operators.

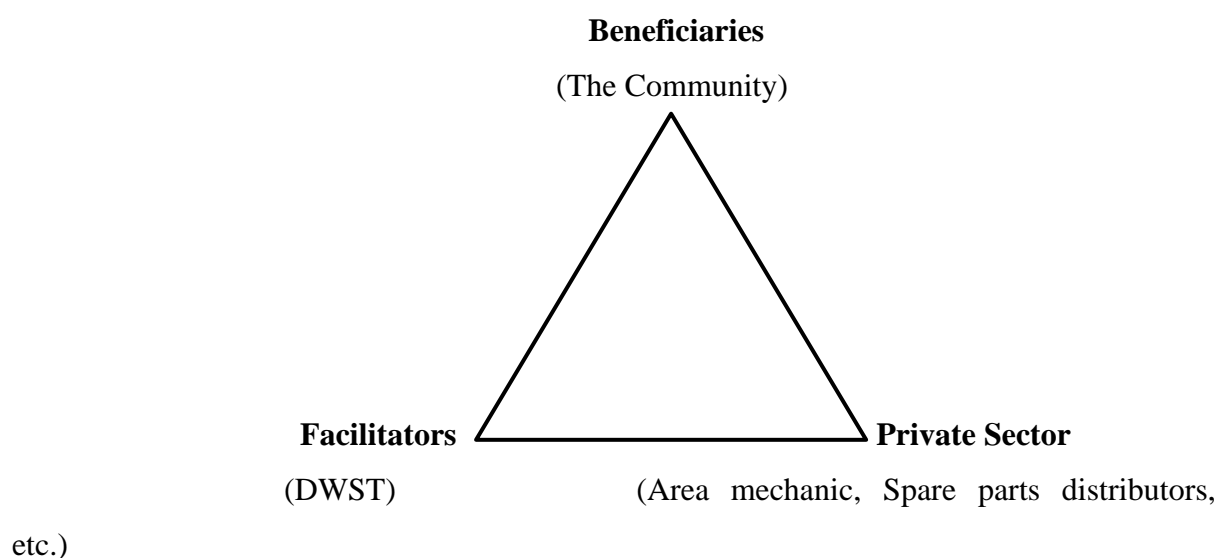


Figure 2.15: Operations and Maintenance Concept of Water and Sanitation Facility
(CWSA, 2012; CWSA, 2000)

2.9.5 Selecting Beneficiary Communities for Supply of Facilities

To select a community within a district to benefit from water and sanitation facility, there is a laid down procedure that District Assemblies follow as illustrated in figure 2.17. This procedure enables the selection process to be devoid of biases or favouritism.

The first step is for the regional Community Water and Sanitation Agency to source for, and receive funding for a project. It then launches the programme at the regional quarters where all the district assemblies within the region are represented.

Following that is the launching at the various district assemblies to explain the processes and procedures especially, the Demand-Responsive-Approach concept to community leaders. This enables each community to apply to the district assembly for their preferred choice of facility with evidence of ability to pay the 5 % capital outlay of the project cost. The selection process then continues as indicated in figure 2.17.

Procedure for Selecting Communities for Supply of Water Facilities

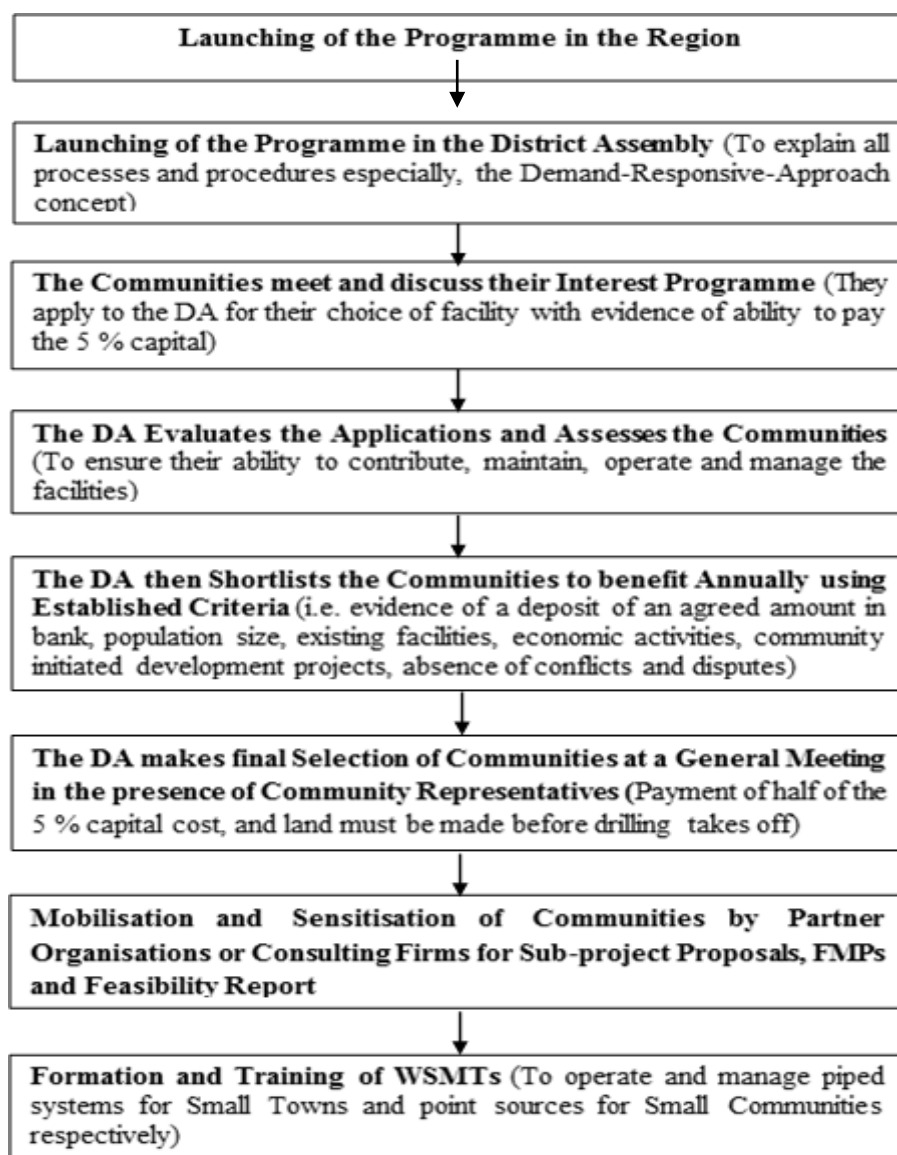


Figure 2.16: Procedures for selecting beneficiary communities for water supply facility (CWSA, 2012)

2.10 Community Water and Sanitation Agency and Its Collaborative Organisations

Ministry of Water Resources Works and Housing (MWRWH) is the main ministry of the water sector responsible for setting water policies and strategies (essentially resource management and supply of drinking water for both urban and rural dwellers). Two key public sector institutions and an agency execute the ministry's functions in the country; namely: the Water Resources Commission (WRC), Ghana Water Company Ltd (GWCL) and the Community Water and Sanitation Agency (CWSA). The ministry also has a Water Directorate (WD) that oversees sector policy formulation and review, monitoring and evaluation of activities of the agencies, and coordination of the activities of development partners. (CWSA, 2012; AMCOW, 2014).

The institutions that collaborate with CWSA are urban water company (GWCL), NGOs, development partners, district assemblies, ministry of health, ministry of local government and rural development and various community water and sanitation management teams (CWSA Corporate brochure, 2012).

2.11 Challenges Confronting CWSA in Carrying out its Mandates

Despite the numerous institutional linkages and measures put in place in pursuance of its mandate, CWSA faces a number of challenges among them are:

- i. Budgetary constraints; it has been reported that CWSA has never received complete allocation of its annual budget from either the Government or its Development Partners. Table 2.8 below gives an illustration in 2011 budget of CWSA.

Table 2.8: Budget Allocation Challenge

Type of Expenses	Budgeted Figure (Million GH¢)	Amount Approved (Million GH¢)	Actual Amount Released (Million GH¢)
Administrative Expenses	3.217	0.485	0.468
Service Activities	3.306	0.037	nil
Investments	51.479	1.901	0.544

CWSA Corporate Brochure (2012)

- ii. Difficult hydro-geological terrain leading to low success rate in borehole drilling and technical challenge associated with mud drilling in some parts of the country.
- iii. Long processes involved in the use of the procurement law leading to delays in execution of projects in the water sub sector.
- iv. Unsustainability of service delivery as a result of difficulty in setting realistic tariffs and government institutions' failure to pay institutional bills coupled with inadequate personnel and logistics for monitoring of operation and maintenance (MOM) of existing systems.
- v. Lack of legal power to enforce guidelines and standards which are attributed to absence of Legislative Instrument to give full legal backing to the Act 564 (CWSA, 2012; MWRWH, 2010).
- vi. Withdrawal of attractive project allowances and retrenchment of staff at the expiration of water and sanitation projects with development partners (Eyramh, 2013).

2.11.1 Prospecting Surface and Underground Water in Ghanaian Rural Water Supply Chain

Gyau-Boakye and Dapaah-Siakwan, (1999) report that groundwater is the main anchor or pillar for rural water supply in Ghana. Their argument has been based on four merits of groundwater. They state firstly, vast aquifers which lie beneath geographically large areas of the country closed to the remote locations where demand for water is high. Secondly, groundwater stored in aquifers is naturally protected from evaporation thus ensuring water security. Thirdly, the water is also protected from pathogens and hence has excellent microbiological and chemical quality which requires little or no treatment. Fourthly, Gyau-Boakye and Dapaah-Siakwan note that groundwater development requires relatively modest capital cost as opposed to conventional treatment of surface waters (Gyau-Boakye and Dapaah-Siakwan, 1999). A high proportion of communities are therefore supplied from groundwater sources; 95% of water supplied to rural communities is from groundwater (CWSA, 2013).

In spite of the advantages, water safety challenges have been reported. Ground water has a high level of minerals, including metallic compounds, this is a serious problem that is

limiting the extent to which this resource can be exploited (MWRWH, 2010; CWSA, 2012). An average of 30 % of wells drilled for domestic water supply in Ghana is reported to contain manganese, iron, arsenic, fluoride, hardness, low or high pH and some other parameters outside the Ghana Standard Authority (GSA) permissible limits (CWSA, 2012). For instance, CWSA (2011) states that for manganese and iron, the GSA's permissible limit is respectively 0 - 0.1mg/l and 0-0.3mg/l for domestic water supply. It is reported that in some parts of Ghana, up to 41.5mg/l of iron and 10.0mg/l of manganese were detected in some boreholes (CWSA, 2011). The poor water quality accounted for about 40 % of the drilled wells getting likely to be abandoned by the user communities while 60 % of the water are used for washing and bathing (ibid, pages 38-39; CWSA, 2012 page 32). Major factors accounting for this varied water qualities are water table fluctuation, weathering and geothermal changes in the geological formations (CWSA, 2011).

2.11.2 Rural Water Facilities used in Ghana

Discussion under this section is centred on water facilities used in rural Ghana.

Hand Pumps

Most of the installed hand pumps used in the country are Afridev (i.e. Ghana Modified Indian Mark II - GMIMII), NIRA and Vernier (foot pump) hand pumps. However, in the Volta Region (where the case study district is located), all the installed pumps are the NIRA and GMIMII hand pumps (CWSA, 2000). Figure 2.18 illustrates these hand pumps. NIRA pumps are used on boreholes with limited depths (20-45 metres). A trained caretaker does repair work on it. Basically, preventive maintenance is recommended to check whether critical parts (bolts and joints) of the hand pump need to be replaced, greased or tightened.

The Ghana Modified Indian Mark II (GMIMII) hand pump has stainless rising mains (pipes) within which a rod reciprocates during pumping operation. To prevent wear and tear occurring on the rising mains, a small plastic device called a centraliser is used to prevent the rod from touching the rising mains. This centraliser wears easily with time; therefore in order to allow water to flow on a regular basis from the pump, the centralizer is replaced from time to time so as not to get damaged. Besides, the GMIMII hand pump has cylinder parts and other components below ground level. These parts are checked and replaced regularly by area mechanics under the supervision of Water and Sanitation Management Team (WSMT). The pump illustrated in the figure 2.18 at the left side is one of the abandoned GMIMII hand

pumps while the NIRA pump is shown at the right side. Due to its design, it is easier to pump water with the GMIMII than the NIRA pump.



Figure 2.17: Samples of the hand pumps-GMIMII (left) and NIRA (right)

The vernier pump is powered by using the human foot. This is not culturally accepted in the Volta region; this pump is therefore not used in the region. A typical Vernier pump is illustrated in figure 2.19. In the next section, a discussion is held on the mechanised systems used in Ghana.



Figure 2.18: A typical Vernier foot pump

Mechanised Water Facility

Mechanised water facility used in Ghana is either grid or generator powered using diesel or petrol as fuel. There are few cases where solar PV is also used to mechanize the boreholes in the country. No solar PV system is found in the case study area.

2.11.3 Promotion of Rural Water Supply

The government's initiative in providing solar PV water systems in some communities facilitates promotion of the technology in the country as it did hand pumps. Some projects implemented by the government have been described in this section. Records from the 2012 Annual Report of CWSA (2013) present the following situational data on some of the work executed nationwide:

The Government was to provide funding from the Consolidated Fund for the delivery of 20,000 boreholes over 5 year period; 2011-2015. At the end of August 2012, 750 boreholes have been drilled out of the revised target of 1,090 and work on the others were being executed.

Ghana Cocoa Board (COCOBOD) provided funding for the construction of 1,120 boreholes with a dual mechanised powering system comprising solar PV and hand pumps at the end of 2012. This was to provide potable water to some rural communities especially cocoa, coffee and shear nut growing areas (CWSA, 2012; CWSA, 2013).

2.12 Operation and Maintenance of Water Supply Facilities

Setting up a borehole involves carrying out hydro-geological studies on site, drilling and construction, borehole logging, hydro-fracturing (if required) and water quality analysis. When the borehole is drilled dry or the yield is marginal, it is hydro-fractured by breaking opened hard rock in the borehole using very high compressed air so as to increase the yield (Prohydro, 2013). Maintenance of water facilities ensures their sustainability.

Sustainability of rural water supply facilities has been a major issue of concern for facility providers since this is the means by which the facilities life span can be prolonged. In the Ghanaian rural water supply system a lot of mechanisms have been put in place to ensure facility sustainability. These have been discussed below.

2.12.1 Community Ownership of Facility

It is only when community members have feeling of ownership of the facility that they may be motivated to take good care of it. The initial contribution they make towards facility outlay and additional investments made for maintaining these facilities and sustaining their operation and prolong life span give the rural people a sense of ownership.

2.12.2 Fund Raising Towards Operation and Maintenance

The operation and maintenance of the facility is mainly the responsibility of the beneficiary community although the district assembly gives technical support. The community raises a fund through saving at least 30 % of the water tariff collected. The fund is used to buy spare parts, chemical, tools and fuel for work; it also helps in hiring area mechanics, caretakers and other private sector people to work on the facilities (CWSA, 2000).

Various methods of tariff collection are used in the communities to generate revenue for the water facilities. The most effective method reported in the Volta region is Pay-As-You-Fetch (PAYF), by paying an agreed tariff for quantity of water fetched (CWSA, 2000).

Another method used is by community members contributing food items (such as gari) per household per week. Others also exchange firewood for water which is later sold. Some communities do communal work on people's farm and the money realised is kept in the water and sanitation account at the bank.

Communities sometimes generate revenue by collecting water tariff based on monthly flat rates (MFR). It is reported that a 96 % success in collecting water tariff by this MFR was achieved in one particular community in the first year but could not be sustained as the figure dropped to 19 % collection efficiency in the following year (CWSA, 2003).

2.12.3 Borehole Rehabilitation

Borehole rehabilitation (flushing out) has been defined as restoring the borehole to its most efficient condition (CWSA, 2000). A borehole should be rehabilitated within every 3 to 6 years (CWSA, 2000) depending upon the hardness of its rock formation. Alternatively, when the borehole shows a sign of blocking at the filter by way of reduced yield, dirty water and excessive wear on the pump parts in contact with the water, the borehole is rehabilitated after

which a pumping test and water quality analysis are done to ascertain the quantity and quality of the water.

2.13 Chapter Summary

To summarise the chapter, a review of literature on water and energy supply in general has been done with emphasis on Ghanaian rural communities. Groundwater has been identified as the major source of water supply but its quality in some areas fall below national and WHO's standards which leads to some boreholes abandonment.

On the other hand, it has been seen that the Ghana's electrification coverage is mainly by grid extensions. While power supply has always fallen short of demand, what is available has been erratic. However, the country is endowed with abundant sunshine which suggests viability of solar energy for water supply to the rural communities. The next chapter discusses the research methods available, the selected approaches and methods used for the current study.

CHAPTER THREE:RESEARCH METHODOLOGY

3.1 Introduction

This chapter 3 discusses both the research design and the actual method employed in the conduct of the current study. It considers the generic background of design, the techniques chosen and the reasons of their choice. The chapter also touches on activities in the current research with particular reference to the case study, experimental and action research approaches adopted. The use of primary and secondary data and triangulation of research methods have also been dealt with. Included in the chapter is the adaptation of the various techniques to the field study and ended with chapter summary.

3.2 Background of Design

Research design, according to Robson (1993), is concerned with turning research question into research projects. He adds further that there exists a strong propensity for both researchers and those who want research to be carried out to assume that there is no alternative to the research approach that they prefer (Robson, 1993; Coley, 2008). Even though research methods and techniques used are determined by the research questions, there would still be a multiple of ways the research could be designed. Robson (1993) states that the strategies and tactics a researcher selects in carrying out a research depends very much on the type of research question the researcher tries to answer. Saunders, Lewis and Thornhill, (2012), in drawing the distinction between research design and tactics state that the design is concerned with the overall plan for the research while tactics are about the finer details of data collection and analysis. As many as eight research strategies are given by Saunders et al: experimental, survey, archival research, case study research, ethnography, action research, grounded theory and narrative inquiry (ibid, p 173). Robson emphasizes three traditional strategies which are experimentation, survey and case studies; he explains that it may be well appropriate to combine two or three without necessarily feeling straight jacketed into choosing one (Robson, 1993).

The first thing to do when starting a research project is to decide on, and to justify the research approach. When the research methodology is properly documented and the reasoning behind its choice justified, it will enhance the understanding of other researchers and facilitate the repeatability of the research work (Coley, 2008).

On the basis of the background, coupled with the objectives of the current research and the research questions, three research strategies will be selected and triangulated in the current study. Triangulation is a technique that facilitates validation of data through cross verification from two or more sources; i. e. by the use of multiple sources as a means of data verification (Lemon, 1998). This is a method that is argued to reduce the threat of researcher and respondent bias (Robson, 1993) and therefore increase the validity of research findings. In particular, it refers to the application and combination of several research methods in the study of the same phenomenon. Figure 3.1 illustrates for instance how data can be triangulated from primary, secondary and literary sources. Credibility of data is guaranteed when data is proven to be valid, reliable and generalisable.

The research strategies in the current study include; experimental research, case study and action research. According to Saunders et al. (2012), experimental research method is principally or exclusively linked to quantitative research design while a case study research may involve quantitative or qualitative research design or even a mixed method that combines both. Action research is exclusively linked to qualitative research design (Saunders, et al, 2012). The next section discusses sources of data.

3.3 SOURCES OF DATA

Data for research purposes can be obtained from primary and secondary sources.

According to Currie (2005), primary research is a research that produces data that are only obtainable directly from an original source. In certain types of primary research, the researcher has direct contact with the original source of the data. Primary data are data that were previously unknown and which have been obtained directly by the researcher for a particular research project.

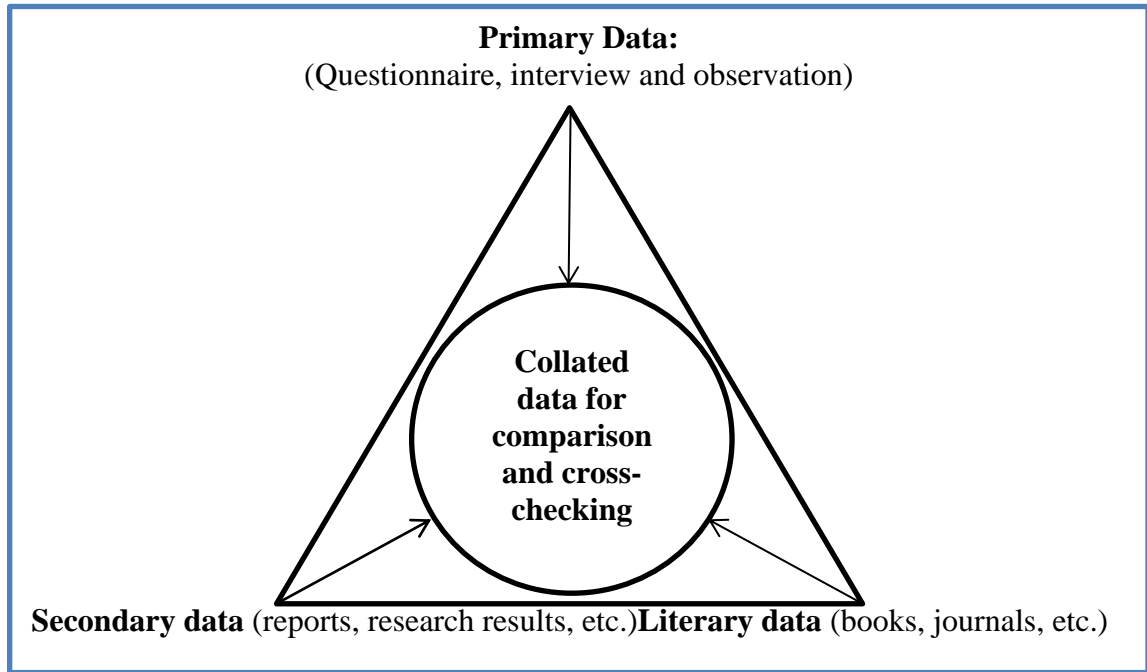


Figure 3.1: Schematic diagram for data triangulation Currie (2005)

There are three main methods possible for primary data collection, these are: the survey method (use of questionnaire), the interview method and the observational method (Currie, 2005).

Secondary data is data collected by one researcher for a specific research, it could be used for another research when the two researches share some common objectives. These second-hand data are referred to as secondary data and they are obtained from other research results, company archives, and more often from reports, papers or if large volumes of electronic data, downloaded from web or emailed personally etc. and from field data of an earlier researcher (whose work will be used by a second researcher). Literary data are those collected from books, journals, all library sources, internet etc.

3.4 Qualitative and Quantitative Research

Approaches to research are generally termed as being either quantitative or qualitative. Creswell citing Newman and Benz (1998) explains that, both of the approaches should not be viewed as polar opposites or dichotomies; instead they represent different ends on a continuum, this assertion has been supported by Saunders et al. (Creswell, 2009; Saunders et al, 2012). They further identify a third approach called mixed method research which incorporates elements of both qualitative and quantitative approaches.

3.4.1 Quantitative Research

According to Coley (2008), quantitative research generally assumes that everything in the social world can be described or measured with a numerical system. It examines relationships between variables which are measured numerically and analysed using a number of statistical techniques. Its usefulness stems from the fact that it allows large amounts of data to be collected and analysed in a logical and replicable way. She explains that this approach is most commonly used in laboratory situations in which the environment and surrounding conditions can be closely monitored and controlled, therefore producing very specific results (Coley, 2008). Quantitative research, as pointed out by Saunders et al (2012) is often used as a synonym for any data collection technique (such as a questionnaire) or data analysis procedure (such as graphs or statistics) that generates or uses numerical data.

This type of research, they note, is generally associated with positivism, especially when it is used with predetermined and highly structured data and data collection techniques. It may also be used within the realist and pragmatist philosophy (Saunders et al, 2012). Creswell (2009) explains that, positivism is empirical science; and that the post-positivists hold a deterministic philosophy about which causes probably determine effects or outcomes. Hence the problems studied by post-positivists reflect the need to identify and assess the causes that influence outcomes, such as found in experiments. May (2001) agrees with Creswell by stating that positivism explains human behaviour in terms of cause and effect and he adds that data must be collected on the social environment and people's reaction to it.

Realism is another philosophical position which relates to scientific enquiry. The essence of realism is that what we sense is reality: that objects have an existence independent of the human mind (Saunders et al, 2012). Realism argues that the knowledge that people have of their social world affects their behaviour and that the social world does not simply 'exist' independently of this knowledge (May, 2001).

McQueen and Knussen (2002) argue that the use of quantitative method nonetheless, may be imperfect or flawed as it is considered as a rigid scientific methodology that ignores or takes some aspects of social life within the 'real world' for granted, and may not allow the use of alternative explanation beyond the hypothesis.

3.4.2 Qualitative Research

Qualitative research tends to study participants in order that the researcher would be able to see the world from the respondents' point of view (Sahota, 2002). By this, a better understanding of the everyday experiences of the participants will be obtained. It also provides the investigator with a clear understanding of the case study area. Creswell (2009) points out that qualitative research is a means for exploring and understanding the meaning individuals or groups ascribe to a social or human problem. He also states that in qualitative research, the intent is to explore the complex set of factors surrounding the central phenomenon and present the varied perspectives of meanings that participants hold. The process involves in-depth, semi-structured or loosely structured forms of interviewing (Creswell, 2009). The three main sources of data associated with qualitative data are: Unstructured and semi-structured interviewing, content analysis and observation (Coley, 2008). Qualitative approach enables the researcher to personally interact with the study and by so doing gains a more personal understanding of the subject area.

Table 3.1: Comparison of Qualitative and Quantitative Research Approaches

Qualitative	Quantitative
Assumptions	
Reality socially constructed	Facts and data have an objective reality
Variables complex and interwoven; difficult to measure	Variables can be measured and identified
Events viewed from informant's perspective	Events viewed from outsider's perspective
Dynamic quality to life	Static reality to life
Purpose	
Interpretation	Prediction
Contextualisation	Generalisation
Understanding the perspectives of Others	Casual explanation
Method	
Data collection using participant observation, unstructured interviews	Testing and measuring
Concludes with hypothesis and grounded theory	Commences with hypothesis and theory
Emergence and portrayal	Manipulation and control
Inductive and naturalistic	Deductive and experimental
Data analysis by themes from informants descriptions	Statistical analysis
Data reported in language of informant	Statistical reporting
Descriptive write-up	Abstract impersonal write-up
Role of Researcher	
Researcher as instrument	Researcher applies formal instruments
Personal involvement	Detachment
Empathic understanding	Objective

Source: (Burns, 2000)

Table 3.1 compares qualitative and quantitative research approaches.

3.5 RESEARCH STRATEGIES

From the eight strategies highlighted by Saunders et al (2012) seen in section 3.2 and based upon the objectives of the current study, the most appropriate which are deemed to be more relevant for the current research are the experimental, case study and action research strategies. Survey research is also suitable but this will be covered in the case study strategy. Grounded theory, ethnography, archival research and narrative inquiry though useful strategies may not be so relevant to the current study. The three strategies considered suitable for the current study are discussed in the following sub-sections.

3.5.1 Experimental Research

Experimental research is a form of research that owes much to the natural sciences, even though its features can be seen in psychological and social science research. Hakim (2000) notes that, experiment enables the probability of a change in an independent variable that causes a change in another variable, (dependent variable), to be studied.

An experiment uses predictions (hypotheses) rather than research questions since the researcher anticipates if a relationship exists between the variables or not. A null hypothesis is one that predicts that there will not be a significant difference or relationship between the variables; it is usually tested statistically. The opposing hypothesis predicts that there will be a significant difference or relationship between the variables (Hakim, 2000). Since there are some independent as well as dependent variables that need to be studied, experimental research will be used as part of data collection strategy in the current work.

3.5.2 Case Study Research

Huberman and Miles (2002) have suggested that, a case study is a research strategy which focuses on understanding the dynamics present within single settings through utilising a combination of data collection methods. The case study strategy has considerable ability to generate answers to the question ‘why?’, as well as ‘what?’ and ‘how?’ Pointed out by Saunders et al. (2012), a case study explores a research topic or phenomenon within its contexts, or within a number of real-life contexts. The emphasis on the “context” has been stressed by Yin (2009) who notes that within a case study, the boundaries between the phenomenon being studied and the context within which it is being studied are not always

clear. In the opinion of Eisenhardt and Graebner (2007), the case study strategy will be relevant if the researcher wishes to gain a rich understanding of the context of the research processes being indorsed. Creswell (2009) notes that in a case study, the researcher explores in depth a programme, event, process, activity and one or more individuals. According to him, the cases are bounded by time and activity requiring a long period of time to collect detailed information employing varied data collection procedures (Creswell, 2009). Saunders et al. (2012) explain that, by using a case study strategy, the researcher is likely to use and triangulate multiple sources of data (i.e. data from interviews, observation, documentary analysis and questionnaire) so as to ensure that the data are telling the researcher what ought to be said.

Yin (2009) explains the differences in four different case study strategies which he compares in two categories:

- i. single case versus multiple cases
- ii. holistic case versus embedded case.

Yin argues that a single case is used when it represents a critical or unique case. On the other hand, a single case may be selected on the basis that it is typical or it provides an opportunity for the researcher to observe and analyse a phenomenon that had been considered by few researchers. A case study method can also incorporate more than one case (multiple cases). The understanding behind the use of multiple cases is to establish if findings from such cases can be replicated. Cases are chosen cautiously so that comparable outcomes are forecast to be produced from each one. This is also called literal replication (Saunders et al, 2012). In the conduct of this research, a case study method will be adopted with the aim of studying the case through an exploratory and explanation approach.

3.5.3 Action Research

As the name implies, action research has to do with both action and research; the action has to do with solving real situational problems and the research has to do with furthering the goal of science, but the action stage must be seen as an integral part of the research itself (Robson, 1993). The research will use case based action research. Being an action research, the investigation is an interactive inquiry process that balances problem solving actions implemented in a collaborative context with data-driven collaborative analysis (Reason and

Bradbury, 2007). Robson notes that action research is sometimes considered a case study in the context of educational research and also in looking at practice in a particular context where a change in that context is required (Robson, 1993). To Saunders et al (2012), action research is defined as “research strategy concerned with the management of a change and involving close collaboration between practitioners and researchers. The results flowing from action research should also inform other context.” (Saunders et al, 2012). In the current study, action research was used to know the dynamics of communities. This study became a continuous investigation in each case setting.

3.6 Research Tools or Techniques

Research tools are techniques which are employed to collect research data. They are interview, questionnaire, observation, experiment, literature search and documentation. These will be used in the current research to collect relevant data. Table 3.2 gives the list of methods to be used and the sources where data will be collected.

3.6.1 Observation Techniques and Limitations

Observation is one of the means by which the actions and behaviour of people can be studied in qualitative research. A natural and obvious technique is to watch what participants do and record this in some way. It will then be possible to describe, analyse and interpret what has been observed (Saunders et al, 2012; Coley, 2008). The manner in which the data is to be recorded is key; so, it is important that data is collected properly and effectively to provide accurate analysis, but this must be done without disturbing the participants (Coley, 2008). Creswell (2009) notes that audio-visual materials such as photographs, videotapes, art objects, computer software and film are used to collect data. Coolican (1999) also suggests that behaviour records can be made using any or a mixture of the following devices:

- Film or video recording,
- Still camera,
- Audio tape (to record spoken observations)
- Hand written notes, ratings or coding on the spot.

Observation may be participant observation and structured observation. Participant observation is qualitative and emphasis is placed on discovering of meanings that people attach to their actions, while structured observation is quantitative and is more concerned

with the frequency of actions rather than why those actions happen; it has a high level of predetermined structure (Saunders et al, 2012).

Since the actions and behaviours of people are the main aspects within the current study, this research adopted in part, participant observation technique; also because the existing water facilities must be studied to see their functionality, a structured observation technique was also made. The main issues for structured observation relating to aspects of reliability are: observer error and bias, participant error, and observer effect (Saunders et al, 2012). Creswell also points out that the use of audio-visuals may be difficult to interpret and that the presence of the observer such as a photographer may be disruptive, intrusive and affect responses; also the audio-visual may not be accessible publicly or privately (Creswell, 2009).

3.6.2 Interview techniques and limitations

In defining interview as a form of conversation, Robson, quoting Cohen and Manion (1989) states it is “initiated by an interviewer for the specific purpose of obtaining research-relevant information and focused by him on content specified by research objectives of systematic description, prediction, or explanation” (Robson, 1993).

Coley (2008), notes that interviewing as a research method is widely used in social research, although there are many different types that the researcher should be aware of. Interviewing typically involves receiving answers from the interviewee and choice of technique usually depends upon the depth of knowledge required.

An interview may be highly formalized and structured, using standardized questions for each research participant called interviewee or they may be informal and structured conversation. In between there are intermediate positions depending on the level of formality and structure used.

Saunders, et al (2012) note that one typology that is commonly used relates to these levels of formality and structure, where interviewees are categorized as either:

- Structured interviews;
- Semi-unstructured interviews
- Unstructured or in-depth interviews (Saunders et al, 2012)

Coley (2008) and Saunders et al, (2012) explain that, fully structured interviewing is often common to quantitative research, since objectives can be predetermined and produce data that is relatively easy to analyse using tested statistical methods. By comparison, semi-structured and in-depth (unstructured) interviews are 'non-standardised'. They are often referred to as qualitative research interview (King, 2004)

Semi-structured interviewing has predetermined questions but the order can be modified based upon the perception of the interviewer about what seems most appropriate. Additional questions can also be posed which further explore the response to the predetermined questions. Semi-structured and unstructured interviews are widely used in flexible, qualitative designs (Robson, 2002).

Unstructured interviews are informal. Using unstructured interviewing method is often viewed as a rich form of descriptive data, because open-ended questioning which encourages free expression on the part of the interviewee and no predetermined set of expectations on the part of the researcher are employed as noted by McQueen and Knussen (2002).

As the current research is partly qualitative in its approach, semi-structured and unstructured interviewing techniques will be adopted. Interviewing poses some special problems for internal generalisability and reliability because the researcher is usually in the presence of the interviewee for a relatively short time about 30 minutes, (Saunders et al., 2012) and must necessarily draw inferences from what happened during that brief period (Huberman and Miles, 2002). In the case of the current research this issue can be overcome, as not only will the researcher be conducting individual interviews with community dwellers but he will also have the opportunity to observe individuals frequently during field visits throughout the research period, thereby verifying the interview results. He will also have the opportunity to re-interview participants for clarification, expansion and validation as and when necessary. Robson (1993) points out that interviewing can be time consuming; and that interview conducted within half an hour is not likely to be helpful while an interview duration over an hour would place an unnecessary demands on the interviewee (Robson, 1993). It may be inferred therefore that conducting interview between a period lasting 30 minutes and one hour may be very ideal and so the necessary precautions will be taken during the actual process in the current research.

Interview may be conducted as telephone interview, face-to-face, focused group and group interview (Saunders et al, 2012; May, 2001; Robson, 1993).

3.6.3 Questionnaire Techniques and Limitations

A questionnaire can be defined as a document having a set of questions in an orderly manner under specific themes based on the research objectives and research questions. This document will also contain instructions as to what are required of the participants referred to as respondents. A statement assuring confidentiality and anonymity of the respondents will also be on the questionnaire.

Self-completed questionnaires are those which the respondents fill in for themselves. According to Robson (1993) if the questionnaire is well constructed, the time needed to code and analyse the responses can be short and the researcher's effort is also made less. This makes the questionnaire a very efficient tool and hence it is used widely. May (2001) supports Robson's assertion by stating that this offers relatively a cheap method of data collection over the personal interview method. May (2001) further points out that the use of self-completed questionnaire as data collecting tool provides people with a medium for the anonymous expression of beliefs; he however notes that when respondents do not have an incentive, either through an interest in the subject or some other basis, the response rate will be as low as about 40 per cent (May, 2001).

Saunders et al., note that the internal validity and reliability of the data collected and the response rate to be achieved depend, to a large extent, on the design of the questions, the structure of the questionnaire and the rigour of the pilot testing a researcher undertakes (Saunders et al, 2012).

In the next sections, the research methods chosen for the current study are discussed.

3.7 Chosen Research Methodology

The study required a mixed method (qualitative and quantitative) approach. Three main methods are used in the current research: Action research (qualitative), Case Studies (qualitative and quantitative) and Experimental (quantitative) as shown in Figure 3.2.

Various tools or techniques necessary in the current study for data collection were used. Table 3.2 gives the list of techniques or tools used to collect the data: literature search, interviews, questionnaire, documentary search, experiment and observations. The table also provides the sources where such data were collected.

The literature search was conducted using scholarly journals, conference papers, articles, theses and books in the area of renewable energy, water access and sustainable development. Interview was the main tool used on the field for community dwellers and key stakeholders in PV and rural water supply chain.

A self-completed questionnaire containing both closed and open-ended questions was designed and used to collect information on rural water supply and energy used including demographic data from respondents who were senior high students in Kpetoe and Ziope. Data were coded and analysed by using Statistical Package for Social Scientists (SPSS) version 16 and Microsoft Excel.

Documentary search was conducted on documents such as Agotime-Ziope District profile, Community Water and Sanitation Agency Corporate Brochure and Magazines, Energy Commission data, documents from the Renewable Energy department of Ministry of Energy-Ghana and many more which were available to the researcher in the course of the field work.

Participant observation was carried out on the people in the communities and structured observation on existing water facilities in some selected communities in the study area to find out their availability and functionality. Video and audio recordings (transcribed) and still photographs were made during the field /site visits.

Data have also been collected from primary, secondary and literary sources. The nature of the study necessitated the use of these data sources and the approaches employed are qualitative, quantitative and the mix of both referred to as mixed method.

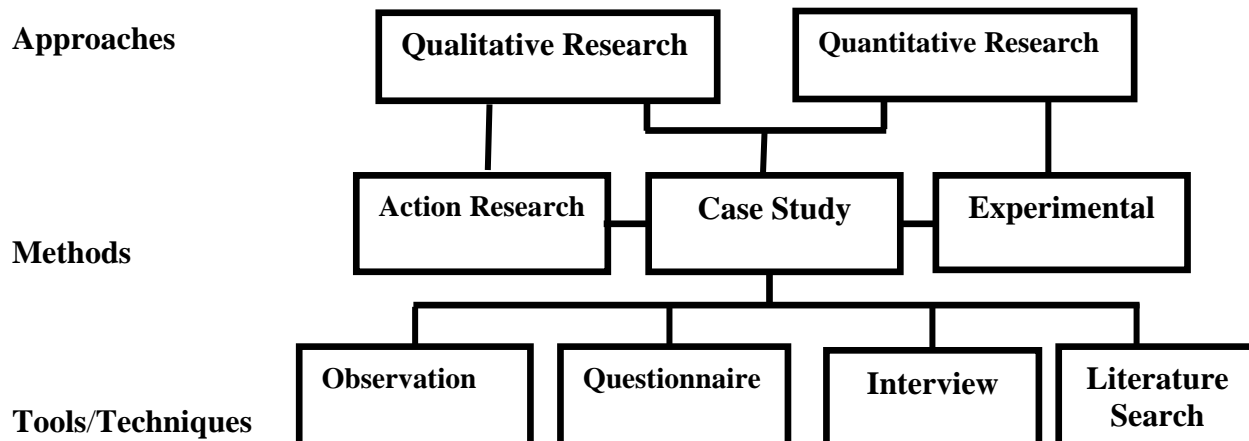


Figure 3.2: Chosen Research Methodology

3.7.1 Action Research Used

In the current study it became necessary to critically investigate the actions and other situations in the case study area in relation to energy use and water access so as to know the dynamics of the communities. The action has to do with solving real situational problems with the people in the case study area while the research has to do with furthering the goal of science, thus using solar PV pumping system as a technology to solve the problem the people face in the access of potable water in the Kporta community. Hence, as one of the methods, the study used action research as a continuous investigation in each case setting where the exploration became an interactive inquiry process.

3.7.2 Case Studies Used

The Agotime-Ziope district was selected for the current study because communities in the district lacked potable water especially in the dry season (December-March) even though there are a number of streamlets in the area. Additionally, the district is naturally endowed with abundant sunshine that produces enough solar energy all year around but only one solar PV water pumping facility could be found in the whole district; all these coupled with non-availability of grid power in some parts of the district, erratic power supply in grid connected communities, long periods of grid power failure justify the importance of the current research to find out what are the factors that militate against the adoption of solar PV for water pumping in the Agotime-Ziope district.

Seven cases have been identified and undertaken; five from the main study area and two cases from outside (Adaklu Anfoe and Lume Avete) it. Figure 3.3 shows the Agotime-Ziope district and the case studies (GSS, 2014).

3.7.2.1 Case Study 1: Kpetoe

The main method used in Kpetoe is case study. The techniques employed were interview (for district assembly senior personnel, water and sanitation development board and women group); questionnaire (for Kpetoe senior high school students) and structured observation (on existing water facilities). Detailed results and discussions are provided in chapters 5 (results) and 7 (discussion) respectively.

3.7.2.2 Case Study 2: Ziope

The second case is Ziope. It is in a similar situation to Kpetoe described above. The same method and techniques employed at case I (Kpetoe) applied in Ziope (questionnaire administered to Ziope senior high school students). Further details can be seen in chapters 5 and 7.

3.7.2.3 Case Study 3: Akpokorpe

Akpokorpe was the third case considered; the methods and techniques used were almost the same as in Kpetoe and Ziope except that no questionnaire was used in this community. Further details can be seen in chapters 5 (results) and 7 (discussion).

3.7.2.4 Case Study 4: Mangoase

Case study method was used with structured observation and interview techniques at Mangoase as the fourth case.

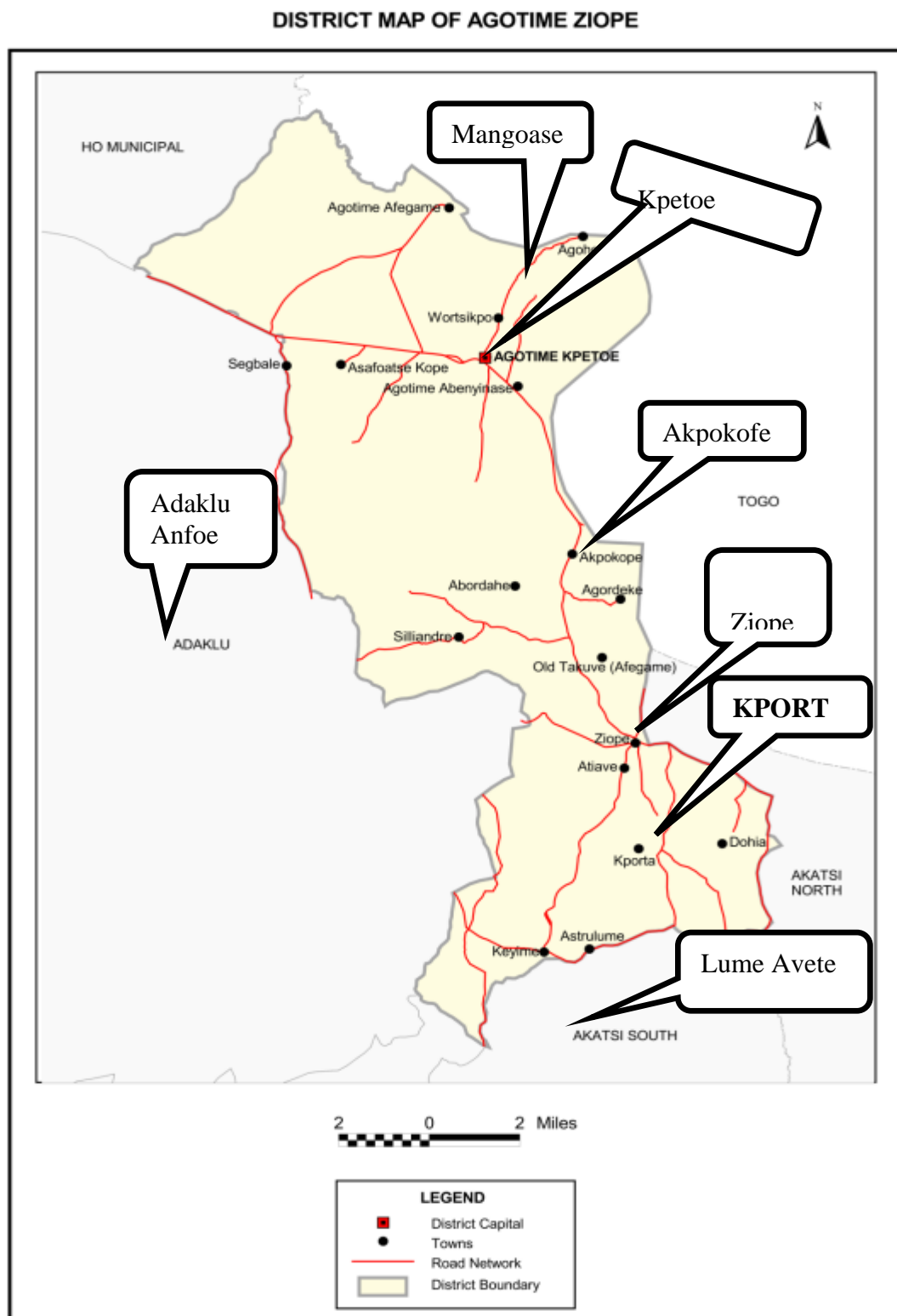


Figure 3.3: Agotime-Ziope District map with case study locations (GSS, 2014)

3.7.2.5 Case Study 5: Kporta

The fifth case is Kporta; the community where the researcher installed a solar PV system. Case study and experimental methods were used. Detailed discussions on Kporta community and the PV system can be found in the chapters 5 (interview results), 6 (experimental and quantitative results) and 7 (discussion of results).

3.7.2.6 Case Study 6: Lume Avete

Lume Avete is a community in the Akatsi south district. A case study method with the use of interview technique were employed. The community was selected to enable the researcher learn some lessons from experiences gained by the inhabitants in the use of a PV water system since 1999.

3.7.2.7 Case Study 7: Adaklu Anfoe

Adaklu Anfoe is a community in the Adaklu district. Just like Lume Avete, the community has since 1999 been using a solar PV water system. A case study method with similar techniques used in Lume Avete applied in Adaklu Anfoe.

In chapter 7, discussions have been made on all these seven communities considered here in relation to socio-economic, cultural and technical factors that influence adoption of PV system in rural Ghana. The discussions provide the relevant information needed for transferability and replication of the PV system elsewhere.

3.7.3 Experimental Research Method Used

Experiment as a research method was used in the current research to enable the researcher collect some numeric data for objective analysis on the use of the solar water pumping system. Some experiments have thus been conducted on the solar PV system and data so collected, (basically quantitative primary data), have been reported in chapter 6. Water quality analysis was also carried out on some samples of water found in the study area. The quality control department of Ghana Water Company Ltd (GWCL), the country's urban water producer, was engaged to do the analysis and the results can be seen in section 5.4

Case Studies in Agotime-Ziope District specifically in Tables 5.2, 5.4, 5.5 and 5.7 for water samples from Kpetoe, Ziope, Akpokorpe and Kporta respectively.

Table 3.2: Data Collection Techniques and Sources Used

Serial No.	Data Collection Techniques	Sources
1	Literature Search	Journals, Conference Papers, Articles, Theses and Books were used to support and add to case study findings
2	Interviews	CWSA, Agotime-Ziope District assembly, WSMTs, community dwellers, key PV industry players and Ministry of Energy
3	Questionnaires	Community Senior High Schools Final year students at Kpetoe and Ziope.
4	Documentation Search	Agotime-Ziope District profile, Community Water and Sanitation Agency Corporate Brochure and Magazines, Energy Commission data, Documents from the Renewable Energy department of Ministry of Energy-Ghana
5	Experiment	Carried out on the installed solar water pumping system. Variable measured were solar intensity volume of water pumped and collected, solar power
6	Observation	Impact of the solar water pumping system on the community dwellers and their perception about the new technology. Performance of existing hand pumps

The following sections discuss access and entry into the case study communities and the main activities that took place in the course of the research.

3.8 Access and Entry into the Case Study Area

The initial exploratory study did at the Community Water and Sanitation Agency office enabled the researcher to plan the project by mapping out where to go for information and who to engage in each community. After the District Chief Executive (e.g. Council Mayor) approved and gave a consent for the research to be carried in the district (about late 2012 and early 2013), the first visits to each of the study communities were done by the researcher in the company of the district engineer and the facility monitoring officer at the Community Water and Sanitation Agency office. This authenticated the researcher's presence in the communities which attracted local people's acceptance and cooperation. For subsequent visits, the community chiefs and their representatives, Water and Sanitation Management Teams (WSDB and WATSAN Committees) were the main contact people in each community the researcher and his team met first on any visit.

Trained research assistants (Teaching assistants and final year Higher National Diploma students in my University) were engaged at various visitations. Apparatus used included digital camera, audio recorder and laptop; the researcher's personal four wheel pick-up suitable for village terrain was used. Arrangements to visit each community was made between the researcher and the respective village contact persons through the use of cell phones and physical visits. Further details are provided under each community visited and reported in chapter 5. Concerning the installation of the solar PV water pumping system at Kpota, both community men and the research jointly got involved the detail can also be seen in chapter 6. The district engineer was engaged from February 2013 till commissioning and hand over of the system in late 2014.

As required by ethics policy, agreed access and entry into the case study community and into any organization used for the research was sought and appropriate consent obtained. This was in the fulfillment of both the Ethics Policy of the De Montfort University and basic research requirements.

The Agotime-Ziope district map has been presented in figure 3.3 showing the locations of the 20 main communities in the district including the five main case studies (Kpetoe, Ziope, Akpokorpe Mangoase and Kpota). The district shares its borders with other districts and Togo. Sharing border on the north-west with the district is the Ho Municipality; on the west is Adaklu district; on the south-eastern side is Akatsi North district and the rest of the eastern border is shared with Togo. The southern border is shared with Akatsi South district.

3.8.1 Entry into Agotime-Ziope District

The researcher booked an appointment with the District Chief Executive (DCE) of the Agotime-Ziope district in order to discuss the whole research work with him. The DCE is the political and the administrative head of the entire district whose official permit was necessary for access and entry into the communities within the case study area. A Participant Information Sheet and a Consent Form, requesting the participation of the District Chief Executive in the research, also informing him about the areas that would be covered during the interview was sent to him to which the DCE consented.

The written consent served three main purposes. Firstly, it was an indication of his acceptance to participate in the study. Secondly, it was used in addition to other consent

forms to process ethics approval form as a requirement from the De Montfort University. Thirdly, his written consent provided official permit that facilitated the researcher's access and entry into the communities where the research was carried out.

3.8.2 Entry into the Case Study Communities

With the DCE's approval, entry into other communities through the community chiefs became easier for the researcher and his team. The research team's first point of call in any community entered was to the chief or his regent when the former was not present or the chairman of Water and Sanitation Management Team (WSMT). The researcher would then explain the purpose of the visit which centred on the research and give out the participant information sheet. The chief or his representative would then schedule a date for the research team to come for a reply. Sometimes cell phone numbers were exchanged to ease correspondence between the two parties and arrangement for meeting with participants was made on a scheduled date.

3.8.3 Entry into the Community Senior High Schools

There are two community senior high schools in the district. Access into the two schools at Kpetoe and Ziope, where data were collected by the use of questionnaire, was sought first by contacting the respective headmasters. Initial visits were paid to the schools on the first day to explain the research work to the headmasters and also to seek their consent for using the students as respondents for the study. Third (final) year students who were deemed to have lived in the communities for at least six years were purposively selected as indicated in section 3.12.1.

3.9 Population for the Study

Population is an entire collection of things or a full set of cases from which a sample is taken. Sometimes, it is impracticable to survey the entire population, especially when there is budgetary and time constraints. In such a situation sampling provides a valid alternative to census. The target population of the study includes all stakeholders in the rural water supply chain and establishments that deal with solar energy technology as indicated in table 3.3. The population identified for this study was drawn from rural communities in the Agotime-Ziope district in the Volta Region of Ghana and solar PV industry players.

Table 3.3: Population for the Study

Serial Number	Target Population
1.	Regional Community Water and Sanitation Agency
2.	Agotime Ziope district assembly and rural communities in case study area
3.	Agotime-Ziope community senior high schools
4.	Solar Energy Companies and Ministry of Energy

3.9.1 Sample Design

A sample consists of those units from the total population which are selected for data collection. The purpose of sampling is to reduce the cost in time, energy and money involved in data collection and analysis. At the same time, sampling could help the researcher to produce more accurate information, as less but sufficient data is collected and analysed, it is likely that fewer mistakes would be made.

Available sampling techniques are divided into two types: probability (representative) and non- probability sampling. Probability sampling are simple random, systematic, stratified and cluster random. These have known chance or probability of each case selected from the population (Saunders et al., 2012).

For non-probability samples, the probability of each case being selected from the population is not known. Examples are quota, purposive, volunteer and haphazard sampling. Saunders et al. (2012) argue that for many research, there will be the need in combining probability and non-probability sampling techniques.

Patton (2002) observes that the sample size selected by a researcher using purposive sampling is dependent on the research questions and objectives; that is on what the research needs to find out, what will be useful, what will have credibility and what can be done within the researcher's available resources (Patton, 2002 cited in Saunders et al, 2012). Where qualitative data using semi-structured or unstructured interview is to be used to address the above concerns raised by Patton, Saunders (2012) provides the necessary guidelines shown in table 3.4 for selecting the most appropriate sampling technique and the sample.

Table 3.4: Minimum non-probability Sample Size

NATURE OF STUDY	MINIMUM SAMPLE SIZE
Semi structure/in-depth interview	5 – 25
Ethnographic	35 – 36
Grounded theory	20 – 35
Homogeneous population	4 – 12
Heterogeneous population	12 – 30

Saunders 2012 cited in Saunders et al, 2012

3.10 Types of Data Used

Both primary and secondary data were used in the research. A case study was carried out to collect primary data in qualitative and quantitative form from the communities sampled for the research. Data on demography, socio-economic status of the community dwellers, energy and on policy issues were collected.

Demographic data collected related to age, sex, level of education and household while socio-economic data related to occupation, sources and usage of water, type of water facility, and water tariff. Technical data collected related to planning and design of water facilities; management, operation and maintenance of the facilities. Sources of power used for water supply and information on solar energy applications in Ghana as a whole were also collected.

3.11 Sources of Data for the Research

Primary data on socio-economic experiences within the sampled communities were collected using mixed approach of quantitative and qualitative data collection methods as seen in table 3.2. Data were collected from sampled communities within the study area and those located outside the study area, the latter served as the counterfactual evidence for effective comparative analyses.

Secondary data/information was captured from publications and the project reports from Community Water and Sanitation Agency, Ministry of Power (e. g. Japan International Cooperation Agency-JICA report) relevant to the research topic. Reference materials which included journals, conference papers, internet sources, books, government publications and from the Adaklu-Anyigbe district profile were also consulted extensively in the conduct of the current research. Adaklu-Anyigbe district was the former district which had been divided into Agotime-Ziope and Adaklu districts.

3.12 Sampling Process

Purposive and simple random samplings were methods used in the current study. The principle of selection in purposive sampling is the researcher's judgment as to typicality or interest. The purposive sampling which is an approach commonly used within case studies (Robson, 1993; Saunders et al, 2012) involves a careful selection of typical cases that represent relevant dimensions of the population (Singleton and Straits, 2010). In this research therefore, the respondents were selected based on the researcher's judgment that those selected were key individuals and groups who could give information required for the study. Since the community water supply situation in the case study area varies from one community to another, it became necessary to identify these variations upon which samples were selected in the current study.

Three intermediary variables were examined: water supply and power usage; type of water facility and quantity of water produced; utility tariff and water facility operation and management.

In selecting the sampling frame, the guidelines in the NCWS programme for rural water provision was also considered in adopting the purposive sampling as explained in the next section.

3.12.1 Sampling Frame

In line with the National Community and Sanitation Programme (NCWSP) as stipulated in the Act of Parliament, Act 564, the researcher has categorised the sample unit into three levels or subgroups as the sampling frame for the sampling design. These are:

Coordinating/Facilitating and Technical Personnel subgroup,
Local Community Supervisory Personnel subgroup
The Community Dwellers

Each of these subgroups is briefly explained below.

3.12.1.1 The Coordinating/ Facilitating and Technical Personnel

This first sampled subgroup included senior management personnel from both the Volta region Community Water and Sanitation Agency (CWSA) and Agotime-Ziope District Assembly (DA).

The personnel sampled at the regional office within the CWSA were the engineer, facility monitoring/inspection officer and a former hydro-geologist of the CWSA. They are coded RWST 1, RWST 2 and RWST 3 respectively in Box 5.1 (see section 5.2 Results from the Volta Region Community Water and Sanitation Agency)

The personnel in the Agotime-Ziope district assembly (i. e. district assembly officials) sampled were the District Chief Executive (DCE), District Coordinating Director (DCD), District Development Planning Officer (DDPO) and the District Engineer (DEng) who is also the chairman of the three member district water and sanitation team (DWST). These are indicated in table 3.5 and are also coded DCE 1, DCD 2, DDPO 3 and D Eng. 4) respectively; (see section 5.2 Results from the Volta Region Community Water and Sanitation Agency).

3.12.1.2 Local Community Supervisory Personnel Subgroup Level

This subgroup includes water and sanitation development boards (WSDB) for small towns (population between 2001-50000 inhabitants) and water and sanitation (WATSAN) committee for small communities (population between 75 and 2000) indicated in table 3.5.

3.12.1.3 Community Dwellers Subgroup

The third subgroup is the beneficiaries in the small towns or the small communities who patronise the water supply services. It includes students in the two community senior high schools, women groups and revenue (water tariff) collectors also indicated in Box 5.1 (see section 5.2 Results from the Volta Region Community Water and Sanitation Agency).

Table 3.5: Sample Frame and Size of Senior CWSA Personnel

S/N	SAMPLE	DESIGNATION	SAMPL E SIZE	POPULATIO N SIZE
1	Coordinating/Fa cilitating personnel	Region: Regional engineer, Facility Monitoring/inspection officer and hydro-geologist of CWSA District Assembly officials (DCE, DCD, DDPO, DWST)	3 4	6 6

Source: Field data, 2013/2014

CHAPTER FOUR: PRESENTATION OF RESULTS FROM QUESTIONNAIRE

4.1 Introduction

This chapter gives the results obtained from the two community senior high schools (SHS) at Ziope and Kpetoe in the study area. The researcher contacted the headmasters of the two schools and from the records, third year students who had their junior high school education in the district before admitted into the senior high schools were selected. A total of 102 self-completed questionnaires were administered to final year (third year) students from these two schools, and all were completed. This group was selected to be those who have lived in the case study communities continuously for at least six years (three years in the junior high school and three years in the senior high school explained below in Box 4.1). It was considered that these students were more familiar with the water and energy situations in the communities and they have a better knowledge for understanding the questions on the questionnaire than their colleagues who did not live in the communities for the six year duration. Also, because in this part of the world, the youth (mainly from 13 to 25 years old) are family members who mostly collect water for domestic use in addition to women.

This first part of the study enabled the researcher to have overview of the energy and water situation in the case study area. It informed the other parts of the study (interview, focus group and observation) which were qualitative in nature (chapter 5).

4.2 Results Obtained from the Questionnaire

This section presents the results obtained from the use of questionnaire with regard to water collection and power supply for water pumping in the case study area.

4.2.1 Demographic Characteristics of the Respondents

Table 4.1 shows the demographic characteristics of the respondents. It can be seen from the table that there are slightly more females (52.9 %) compared to the males (47.1 %). In the communities, females traditionally perform most of the house chores such as collection of water, washing clothing and cooking for the family which require water. However, the practice has changed in recent times and young men have also started performing these chores especially in the southern part of the country.

Table 4.1: Demographic Characteristics of Respondents

Characteristics	Frequency	Percentage
<i>Gender</i>		
Male	48	47.1
Female	54	52.9
<i>Age bracket (years)</i>		
16 - 19 yrs	59	57.8
20 - 26 yrs	37	36.3
27 yrs & above	6	5.9
<i>Level of education*</i>		
Second Cycle (SHS)	96	94.1
Basic School (JHS)	6	5.9
<i>Marital status**</i>		
Married	7	6.9
Single	95	93.1

For (* and **), refer to Boxes 4.1 and 4.2 respectively for explanation

Box 4.1: Level of Education and Age in the Ghanaian Context

In Ghana, basic school starts from kindergarten of two years, through six years of primary school and three years of junior high school (JHS). In a normal situation, a child starts kindergarten at age 4 and completes JHS at the age of 15 years. The child proceeds to second cycle school (if he passes his Basic Education Certificate Examination-BECE) which may be a senior high school (SHS), technical or vocational institute for another 3 years. Therefore, if he is academically good, the child would have been 18 years at the time of completing a second cycle school in the ideal situation. Children from wealthy families who attend preparatory schools may complete SHS at an age even less than the 18 years. However, in a village setting, a child may start class 1 at the age of about 8 or 10 years since he has to walk long distances (from 1 to 5 km) to school. In some situations, a village student in JHS or SHS coming from a very poor home may have to stop schooling for some time so as to farm and save enough money before continuing his education. The student would therefore finish school (SHS) when he or she is much older than 18.

Box 4.2 Marital Status in the Ghanaian Context

Also in Ghana, marriage does not necessarily apply to only couples who in the developed countries may be referred to as matured adults. Four types of marriage (traditional, Moslem, ordinance and church wedding) are statutorily recognized among matured (18 years and above) men and women for which a dowry must first be paid to the woman's family. However, an unofficial type also exists. This occurs when a man or a boy who is capable of impregnating a woman would have a child with the woman without necessarily paying any dowry to the lady's family; yet they will be regarded as married couple. This happens mostly among peers in JHS and SHS, particularly in the villages. The 7 respondents indicated in the table 4.1 under marital status were likely to fall in this last category of marriage.

4.2.2 Socio-Economic Information on Respondents

Within this subsection, the results obtained on the socioeconomic characteristics of the respondents are presented.

The study further revealed (table 4.2) that youth group (between ages of 16 and 25 years) forms majority (76.5 %) of people who usually collect water in these communities. It is made up of female youth (50%) and male youth (26.5%). Women are the next group of people who collect water for domestic use while the male adults constitute the minority of those who collect water in the households. The trend shown is not surprising for the reason that, because of farming activities in the communities, both men and women together with their children go to farm but the women and their children return earlier to get the house chores done (including collection of water and cooking) before the men return home later in the evening.

Table 4.2: Category of People who fetch water

Which categories of people usually go out to fetch water for domestic use?	Frequency	Percent (%)
Female youth	51	50.0
Male youth	27	26.5
Women	18	17.6
Men	6	5.9
Total	102	100.0

From table 4.3, it has been shown that farming is the major occupation of the people indicating 65 %, followed by Kente weaving (26 %) in the communities within the case study area. Access to adequate water would possibly promote year-round irrigation farming in the area.

Table 4.3: Occupation of Community Inhabitants

What is the major occupation for people in your community?	Frequency	Percent (%)
Farming	66	65
Kente Weaving*	27	26
Teaching	1	1
Fishing	1	1
Trading	4	4
Non Response	3	3
Total	102	100.0

**Kente is hand woven designed local cloth used mostly on important occasions in Ghana*

Table 4.4 illustrates the expenditure level of the people in the communities. It can be seen that most of the inhabitants (74.5 %) are poor and spend below GH¢ 120 (equivalent to about 37 US dollars) per month. It is to be expected however that the figures may be a bit higher (if cost of food stuff collected from farms is included) since food stuff is not included in the monthly expenditure shown in the table.

Table 4.4: Expenditure Level per Month

What is the level of your monthly expenditure (GH¢)?	Frequency	Percent (%)
Below 90.00	37	36.3
90-120	39	38.2
Above 120	26	25.5
Total	102	100.0

1 US dollar = GH¢ 3.21

4.2.2 Water Supply in Study Area

In this section, the results obtained on the water supply situation in the study area are presented.

Table 4.5: Main Source of Water

State the main source of water supply for drinking in your community	Frequency	Percent (%)
Dam	19	18.6
Borehole	42	41.2
Hand-dug well	6	5.9
Stream / River	20	19.6
Piped	5	4.9
Rain Water	10	9.8
Total	102	100.0

It can be seen from table 4.5 that the main sources of water in the case study area are ground and surface water, constituting 47.1 % and 38.2 % respectively. The pipe-borne water source is either a river/stream (as in Kpetoe) or a dam (as in Ziope) both being surface water. Rain water (9.8 %) is harvested mainly in rainy seasons. This pattern is expected of rural setting.

Table 4.6: Purpose for Water Use

What do people in your community use water for?	Frequency	Percent (%)
Domestic	98	96.1
Irrigation	3	2.9
Livestock	1	1.0
Total	102	100.0

Table 4.6 indicates that almost all the water is for domestic purposes; only 3 people (2.9 %) said they use water for irrigation purposes.

Table 4.7: Cleanliness of Water Source

Is the source of water stated in earlier good for drinking?	Frequency	Percent (%)
Yes	47	46.1
No	54	52.9
No Idea	1	1.0
Total	102	100.0

Table 4.7 indicates that slightly more than half the respondents (52.9%) stated that their sources of water were not clean, (i.e. the water is unhygienic).

Table 4.8 shows that a little more than half (50.9 %) of the respondents did not have any idea about how unhygienic water in their communities was treated to make it safe for use in their households. The table however shows that 48 % of the respondents gave various methods by which the unhygienic water was treated. These methods were; addition of alum (chemical) or moringa (a type of herb) to allow mud in the water to settle down; boiling; filtration, and exposure of the water to atmospheric air (aeration).

Table 4.8: Methods of Unwholesome Water Treatment

If the source of water is not good for drinking, how do you treat it?	Frequency	Percent (%)
Adding alum / moringa	12	11.8
Boiling	17	16.7
Filtration	17	16.7
Exposure to sunlight (atmosphere)	4	3.9
No Idea	52	50.9
Total	102	100.0

Table 4.9: Adequacy of Source of Water

Is the source of water adequate in terms of quantity?	Frequency	Percent (%)
Yes	15	14.7
No	87	85.3
Total	102	100.0

The study further revealed, as has been illustrated in table 4.9, that most of the respondents (85.3 %) said the quantity of water was inadequate.

Table 4.10: Purchase of Water

Do you pay for Water?	Frequency	Percent (%)
Yes	79	77.4
No	22	21.6
Non Response	1	1.0
Total	102	100.0

The responses from a total of 77.4 % of the respondents shown in table 4.10 indicate that the people pay for water they fetch from their water facilities while 21.6% indicated they did not. It was revealed from the field that communities having rivers and streams, people collect water without paying for it. Indeed, every community provided with water facilities has been educated to pay for water so as to generate revenue for maintenance and repairs of the facilities. This is an aspect of the principle of community ownership and management of the water facilities for sustainability.

Table 4.11: Mode of Payment for Water

How do you pay for water?	Frequency	Percent (%)
Pay- as –you-fetch	75	73.5 (95 % of valid responses)
Fixed monthly levy	4	4.0
Non Response	23	22.5
Total	102	100.0

From the table 4.11, it can be seen that of those who said they pay for water, 95 % of the valid responses use “Pay-as–you-fetch” mode.” This confirms the earlier research by CWSA and which has become the recommended mode of collecting water tariff as already stated in chapter 2. Usually, trained sales agents engaged by water and sanitation management team (WSMT) sell the water at the facility (borehole fitted with hand pump or mechanized) in rural communities. In small towns where there are usually piped schemes, water flow meters are connected to the pipeline at the water collecting points to record the quantity of water collected. In this case, tariffs collected by the sales agents are matched against the readings made on the flow meter by a supervisor also appointed by the WSMT on regular basis (weekly or monthly). The WSMTs have employed members of staff of whom some are permanent employees on monthly salary and others are casual staff who are on commission, usually between 10 % and 20 % of total sales made.

Water collectors from facilities, whether students/pupils, young or old have to pay for the quantity of water fetched so that the seller can render correct account to his/her supervisor. Hence students/pupils who are sent to collect water are given enough money by whoever sends them (parents, guardians, or class teacher) to pay for the quantity of water he or she fetches.

Table 4.12: Use of Water Tariffs

What is the water tariff used for?	Frequency	Percent (%)
Maintenance / Repairs	59	57.8
Personal gains	2	2.0
Community Development	8	7.8
Bills payment	4	3.9
Treatment of water	4	3.9
No Idea	25	24.5
Total	102	100.0

About the uses of the tariff, respondents believed that the tariff realized from sale of water is used for repair and maintenance of the facilities (57.8 %) and for community development (7.8 %) both totaling 65.6% as indicated in table 4.12. The table further shows a total of 9.9 % of the respondents stated other uses of the water tariff such as water treatment, payment of bills and personal gains.

Table 4.13: Cost of Water

How much does 18 litre bucket of water cost?	Frequency	Percent (%)
GH 0.05p	9	8.8
GH 0.10p	31	30.4
GH 0.20p	29	28.4
GH 0.30p	4	3.9
GH 0.40p	2	2.0
GH 0.50p	1	1.0
No Idea	26	25.5
Total	102	100.0

GH¢ 3.21 = 1 USD; 2013-2014 But GH 100p =GH¢1

Table 4.13 illustrates responses on how much the community inhabitants pay for one 18 litre bucket of water. From the table, 30.4 % of the respondents indicated that they pay 10 pesewas (GH¢ 0.10) for an 18 litre bucket of water while 28.4% said they pay 20 pesewas (GH¢ 0.20) for the same quantity of water.

Generally, the cost of one bucket (18 litre) of water as indicated in the table 4.13 ranges from GHC 0.05 to GHC 0.5. This is because, the results from the case by case studies reported in Chapter 5 revealed that the cost of water varies from community to community within the Agotime-Ziope district. A summary of the cost of water across the communities can be seen in Table 5.10.

Table 4.14: Quantity of Water Used Daily

How much quantity of water do you use per day?	Frequency	Percent (%)
1 - 2 buckets	88	86.3
3 or more buckets	11	10.8
Non Response	3	2.9
Total	102	100.0

From table 4.14, 86.3 % of the responses indicate that each person uses between 1 and 2 buckets of water on the average per day. The situation is almost the same with the women. From the study, it has been noted during focus group discussion (FGD) with women group that women use almost the same quantity of water about 2 buckets of water on the average daily.

4.2.3 Type of Water Supply Facility Used

Presented in this subsection are the results on the water facilities used within the district and their performance as indicated by the respondents.

Table 4.15: Type of Water Facility Available

What type of water facility do you have in your community?	Frequency	Percent (%)
Mechanized piped system	55	54.0
Gravity fed water system	20	19.6
GWCL connection	18	17.6
Dam	3	2.9
Stream / River	2	2.0
Non Response	4	3.9
Total	102	100.0

Table 4.15 shows the type of water facilities found in the respondents' communities.

54% of the respondents stated that they have mechanized piped system, 19.6% mentioned gravity-fed water system and 17.6% stated Ghana Water Company Limited (GWCL). GWCL is the public company responsible for urban water supply. Until 1994, the company was responsible for both rural and urban water supply and had community water and sanitation

division responsible for rural water supply. In 1998 when the CWSA became fully autonomous, it was separated from the GWCL so that the Agency takes full responsibility of rural water supply, sanitation and hygiene issues. Communities which have the GWCL pipelines still use them under CWSA.

Table 4.16: Water Supply Year Round

Do you get enough water supplies all year round with the community's facility?	Frequency	Percent (%)
Yes	15	14.7
No	83	81.4
Non Response	4	3.9
Total	102	100.0

Water supply situation in the case study communities is seasonal for most people. From table 4.16, it has been shown that 81.4% of respondents indicated the people do not have water supply year round. During this period of water scarcity, life becomes difficult for the inhabitants in this area.

Table 4.17: Maintenance of the Facility

In your opinion, who maintains the facility?	Frequency	Percent (%)
The Community / Opinion leaders	74	72.5
Assembly Man	9	8.9
Member of Parliament (MP)	2	2.0
Nobody	4	3.9
Non Response	13	12.7
Total	102	100.0

Table 4.17 illustrates the responses from the respondents about who is responsible for the maintenance of water the facilities. The table shows that the maintenance and repairs of the water facilities in the communities are carried out under the supervision of the respective chiefs and opinion leaders through their WATSAN committees and WSD boards; this has been indicated in the table with a percentage of 72.5%. Clearly this should be expected because the responsibility of management, maintenance and repairs of the water facilities is vested in the elected water and sanitation management teams (WATSAN committee and/or

WSDB) of each community or small town. However 12.7% of the respondents could not provide any response.

4.2.4 Results on Power Supply for Water Pumping

Results on power supply for water pumping in the study area as indicated by the respondents are presented in this subsection.

Table 4.18: Source of Power Supply for Water Pumping

Do you know the source of power for water supply your community?	Frequency	Percent (%)
Yes	59	57.8
No	39	38.3
Non Response	4	3.9
Total	102	100.0
<i>Types of Power Supply</i>		
Generator	4	3.9
National electricity (grid)	57	55.9
Man power	41	40.2
<i>Frequency of Power Supply</i>		
How regular (often) is the power supply?		
Daily	57	55.9
Weekly	8	7.8
Daily but intermittently	37	36.3
Total	102	100.0

Most of the respondents (55.9 % -57.8 %) said that they knew the source of power used to run their communities' water facilities and that, the power is from the national grid (Table 4.18). The supply of power as shown in the table is on daily basis. However, there are times that the supply from the national grid is not stable but erratic. As a result of this, the supply of water to communities with piped system or connection and those with mechanized water supply facility are adversely affected.

Table 4.19: Preference for Solar Energy for Water Pumping

Would you like to use solar power to meet your water supply needs?	Frequency	Percent (%)
Yes	91	89.2
No	3	2.9
Don't know	6	5.9
Non Response	2	2.0
Total	102	100.0

Table 4.19 shows responses about the preference of solar energy for water pumping. Most of the respondents (89.2 %) mentioned that they prefer solar energy to other sources of power for pumping water. However, 5.9 % of them indicated that they had no idea.

Table 4.20 shows respondents' reasons for preferring solar energy as a source of power supply for water pumping. Those who said they prefer solar energy said the reasons behind their choice are that it is regularly available most of the time and its supply is constant and cheap. Others said they prefer solar energy because of the frequent power outages resulting from grid power rationing Ghanaians were experiencing for over two years. It could be that the students may have read about solar energy as one of the energy sources since it is in the junior and senior high schools syllabuses. However, as shall be seen in chapter 5; women groups in Kpetoe, Ziope and Kporta particularly said they do not know about solar PV.

Table 4.20: Reasons for Preferring Solar Power for Water Pumping

Give reasons for your preference of solar energy for water pumping	Frequency	Percent (%)
Availability / Regularity of power	38	37.3
Adequate / constant supply	27	26.5
Frequent power outage	7	6.9
Cheaper / Regular	17	16.7
No supply when solar spoil	2	1.9
Expensive	1	0.9
Non Response	10	9.8
Total	102	100.0

4.4 Chapter Summary

The results obtained from the questionnaire have been presented. Data included demography, rural water supply issues and the available power supply in the district. From the study, it has been revealed that farming is the major occupation of the people in the district with kente weaving being the next.

Groundwater is the main source of water supply in the Agotime-Ziope district and it is accessed through borehole fitted with hand pumps. Water from surface water sources (dams, rivers and streams) is also accessed for domestic use but it is unhygienic and supply has been inadequate year round. The unhygienic water is treated by methods of boiling, adding of alum and moringa or exposure to the atmospheric air for aeration to take place. There is also the possibility of some people using the unhygienic water in its untreated state.

Youth within the age bracket of 16-26 years (mostly female) are people who collect water for domestic use while men are the least of those who collect water. Water accessed through improved sources are paid for, and the most preferred method of revenue generation is “pay-as-you-fetch”. The study revealed that the cost of water per bucket (18-litre capacity) ranges between GHC 0.05 and GHC 0.5 within the district.

Power for water supply is a challenge in the off grid locations; even in some small towns which are grid connected, supply has been erratic which further worsens the poor water supply situation in the district most especially at Kpetoe.

Cost of water in case study communities, water treatment and issues relating to power use and the need for data triangulation necessitated the use of qualitative study which result is presented in the next chapter.

CHAPTER FIVE: PRESENTATION OF QUALITATIVE RESULTS

5.1 Introduction

In this chapter, the results of the qualitative case studies are presented. These were from data collected through interviews (community meetings, focus group discussions-FGD, face-to-face) and observations. There were four sets of interviews:

Interviews with officials: these were in Volta Region Community Water and Sanitation Agency (CWSA), solar energy industries and the Ministry of Energy. The fourth set was interview with case study communities. Five cases within the main Agotime-Ziope case study area: Kpetoe, Ziope, Akpokorpe, Mangoase and Kporta (the community where the solar PV system for the current research has been installed).

Two cases were outside the Agotime-Ziope case study area: Lume Avete in the Akatsi South district and Adaklu Anfoe in the Adaklu district in the Volta region. These were selected because solar PV water pumping systems have been in operation for over 15 years.

5.2 Results from the Volta Region Community Water and Sanitation Agency

The Volta region Community Water and Sanitation Agency (CWSA) has been a key source of information for this study, particularly during the exploratory studies in February 2013. The Agency has always been consulted anytime it was deemed fit during the course of the research. The regional works engineer and the facility monitoring/inspection officer have been the main contact persons. A consultant who is a former hydro-geologist of the CWSA (now chief executive officer of Prohydro, a private consultancy firm) also participated in the study. However, most of the technical information received can be found in the corporate brochure and other documents of the Agency which the researcher included in the list of references. Box 5.1 shows codes used for those interviewed in CWSA and in the case study communities and Box 5.2 shows those from the industry players of the PV.

Box 5.1 Codes Used for the Interviewees in Case Study Communities

Regional CWSA

RCWS 1- Regional Engineer at the CWSA

RCWS 2- Regional Facility Monitoring Officer

RCWS 3- Former CWSA hydro-geologist/chief executive of Prohydro Ltd.

Agotime-Ziope District Assembly Senior Personnel

DCE 1 District Chief Executive; DCD 2 District Coordinating Director

DDPO 3 District Development Planning Officer

DEng 4 District Engineer/Chairman, Water and Sanitation Management Team

Kpetoe Water and Sanitation Team (WSDB) and Women Group

KpWB 5 Chairman - Water and Sanitation Development Board

KpWB 6 Secretary - Water and Sanitation Development Board

KpWB 7 Area Mechanic - Water and Sanitation Development Board

KpWB 8 Senior Pump Mechanic/Pumping Station Attendant

KpWB 9 Accountant and Water Tariff Collector

KpWB 10 Revenue Office of the WSDB; KpWB11 Water Seller.

KpWG 12 1st Interviewee from Kpetoe Women Group

KpWG 13 2nd Interviewee from Kpetoe Women Group

Interviewees in Ziope Community

ZpWS 1 Chairman - Ziope WATSAN committee/Representative of Ziope Chief

ZpWS 2 Business Executive Officer of the NGO

ZpWGi 4 Ziope Women Group member

Interviewees at Akpokofe

AkWS 1 Regent of Akpokofe; 2 AkWS WATSAN committee secretary

AkpWS 2 1st Water Seller at Akpokofe; 4 AkpWS 2nd Water Seller at Akpokofe

In Kporta Community

KpoWS 1 Chairman – water and sanitation committee;

KpoWS 2 – Vice Chairman

KpoWS 3 – Secretary; KpCm 1- Member from Kporta Community

In Mangoase Community

Mang 1 Chief of Mangoase

In Lume Avete Community

LumWS 1 - PV attendant in Lume Avete;

LumWS 2 - WATSAN committee member

LumWS 3 - Women leader;

LuCom 1 - Com Member

LuCom 2- Com Member

LuCom 3 - Com Member

LuCom 4 - Com Member

In Adaklu Anfoe community

AdAf 1 – 1st contact Chief of Community

AdAf 2 – Community Member

AdAf 3 – Community Member

AdAf 4 – Community Member

AdAf 5 – Community Member

5.2.1 Function of the Volta Region CWSA

An interview was conducted with the regional works engineer on 19th February, 2013. This was done face to face in his office at the regional Community Water and Sanitation Agency. Similar interview was conducted with the facility monitoring officer also at the Agency on the same day.

From the interview conducted with the regional works engineer (RCWS 1) and the facility monitoring officer (RCWS 2) of the Agency, the study revealed that the function of the Agency is to facilitate the provision of safe drinking water and sanitation related activities coupled with hygiene education. CWSA works with the districts through district water and sanitation teams (DWST) in every district. The DWST is made up of the district works engineer (being the chairman), community development officer and environmental health officer. The team prepares project plans for the district and the CWSA prepares plans for the needy communities. All such plans are verified on the ground by Regional Verification Team.

Concerning project implementation, the regional works engineer (interviewee RCWSA 1) said geophysicist does the feasibility studies and siting for boreholes fitted with hand pumps; there are also other consultants who do siting for mechanised systems. Features included in the feasibility study are:

- i. Siting of strategic components (overhead reservoir and distribution or delivery lines);
- ii. Population of beneficiary community;
- iii. Location/position of stand pipes
- iv. Water yield matched with population size

When this is done and total costing is made, then a financial support is provided by a funding agency (usually a development partner/donor) through the CWSA as the sole agency representing the government of Ghana.

Usually, before the actual construction of a borehole, the CWSA supports the district assembly to carry out community animation, sensitisation and mobilisation of fund (i.e. when the communities used to provide 5% of the project outlay).

Obviously, the regional CWSA plays facilitating and coordination roles and serves as a link between the funding agencies and the district assemblies. It is thus appropriate that projects

that are implemented within the region should pass through them to facilitate and enhance proper documentation and data keeping on projects executed in the whole Volta region.

5.2.2 Technology Options Used in Rural Water Supply

The CWSA provides the following types of water supply technology options and design criteria:

- i. Point Sources for small communities with population between 75 and 1,200 people Options: hand dug well fitted with hand pumps, borehole fitted with hand pump and rain water harvesting
- ii. Piped System for small communities with population between 1,201 and 2,000 Options: Mechanised borehole with limited distribution points
- iii. Piped Schemes for small towns with population between 2001 and 50, 000 Option: ground water based piped schemes; small conventional treatment schemes, surface water with slow filtration piped schemes etc.

According to interviewee RCWS 1, the Legislative Instrument (LI) establishing CWSA provides that for 75-300 people, hand dug well be provided with hand pump; NIRA pump is used for communities having high water table (shallow well, depth of up to 45m). For deep well, Afridev hand pump and Ghana Modified Indian Mark II are used. This was confirmed by interviewee RCWS 2; he added that there is another facility called Vernier pump. However, this is a foot pump and as such the people in the Volta region do not culturally accept it, so it is not used in the region but could be found in other regions.

With the design criteria, the study revealed that the standard water consumption value used in design is a little over one bucket (20 litres) per capita per day. A community with a population less than or equal to 150 people is to be supplied with one hand dug well; while borehole fitted with hand pump is supplied to community with a population of about 300 people.

5.2.3 Rural Water Supply Operation and Management

Regarding operation and management of water supply systems, the RCWS 1, explained that one of the principles of NCWSP is sustainability of water and sanitation projects and facilities. This according to him is looked at from three perspectives: technical, financial and managerial sustainability.

He said on the technical side, spare parts stores are provided at strategic locations in the country for easy accessibility; area mechanics are trained to repair facilities (especially hand pump parts which are below the ground) within a designated zone; and women caretakers are also trained to do minor maintenance work on facilities (such as greasing of pump parts which are above the ground) in every beneficiary community.

About financial sustainability, facility user fees were instituted where various payment modes were adopted such as “pay-as-you-fetch”; fund raising to meet operation and management of facility (e.g. contribution of food stuff for sale) or fixed monthly levies. Both interviewees (RCWS 1 and RCWS 2) in separate interviews said the “pay-as-you-fetch” is generally accepted as the best method for generating revenue for operating and maintaining the systems.

On the part of facility management, the study revealed that a strong management team (WATSAN or WSDB) put in place coupled with well documented Facility Management Plan (FMP) and cooperation from the people in the communities will facilitate sustainability of the systems.

Donor supports, especially from DANIDA, were strong within the project period ranging between 1993 and 2012. Within this period, employees were paid generous project allowances in addition to their salaries. Districts were zoned for effective monitoring and supervision of facilities and projects. Owing to the supports, water and sanitation management teams were active with their mandates and facilities were sustained. However, when the projects were completed and development partners withdrew their supports, the management of facilities declined. This became a grave concern for DANIDA employees.

This concern was also expressed by the two interviewees and a third participant (RCWS 3) who was a former employee of the CWSA in the Volta region. The hand over and subsequent transfer of projects was done in stages but the final transfer was in 2012 when the project contract between the government of Ghana and DANIDA completely ended.

It was revealed that salaries paid by the Ghana government were consolidated and all the project allowances enjoyed by the employees during DANIDA period were removed. Some employees were laid off and some voluntarily resigned and went into private consulting (one of them is the chief executive officer of Prohydro Ltd-former hydro-geologist of CWSA) who is coded RCWS 3 in the current study.

5.2.4 Availability of Solar PV Water System

To provide answer to the question with regards to availability of solar PV water system in the Volta region, the regional engineer (RCWS 1) said there were a small number (14-17) of solar- paddle systems (solar-paddle was a system that had a hand paddle which people used to pump water in the absence of sunshine) supplied in 1997 by an NGO (31st December Women Movement) meant for farm houses. During sunshine hours, the system was powered by the sun and so the paddle was not used; however the systems worked for a couple of years and then failed. According to him (RCWS 1), three solar PV systems were installed by DANIDA at Lume Avete, Adaklu Anfoe and Aborlove around 1998; they have since been working (except the one at Adaklu-Anfoe). This was confirmed by the monitoring officer (RCWS 2) during his interview, and who later took the researcher on study tour to Lume Avete. Afterward, the researcher and his research team went to Adaklu Anfoe to conduct a study in the community as reported in chapter 3 and section 5.5 of this chapter.

It was revealed during the interview that the CWSA was installing 73 Aqua Solar pump supplied by Ghana Cocoa Marketing Board (COCOBOD) in the Volta region; but none of the pumps was installed in the Agotime-Ziope district which is the case study area for the current research.

5.2.5 Challenges Faced in Rural Water Supply

Among the challenges identified by interviewees is difficult hydro-geology which makes access to water during drilling of a borehole very difficult. This leads to marginal water access (where the yield is about 10 litres per minute) or dry yield (no water accessed). Usually, acceptable yield should be more than 13.5 litres per minute according to (RCWS 1). The same view was expressed by the former hydro-geologist of CWSA (RCWS 3) who added that in such a situation of dry yield, hydro-fracture is done with high pressure compressed air to break open rocks within the borehole as explained in chapter 2.

He also added another challenge that drilling contracts are sometimes awarded to companies without assigning supervising consultants to supervise the work. In this case, the contractors may do substandard work; especially if they are drilling on difficult hydrogeological site.

A third challenge stated by RCWS 1, is siting facility at places which used to be graveyard, household rubbish dump or evil forest zone (this is a reserved forest where the gods are believed to be dwelling and/or burial place for those who died through accident; such as

motor accident). These places are forbidden spots to site water facility. In this case, it is necessary to listen to the choice of place selected by the beneficiary community else, the people would not make use of the facility if sited at such places.

A fourth challenge stated by RCWS 1, is squandering of revenue generated from the sale of water by those who handle such monies if proper control mechanism is not put in place.

Another challenge he mentioned is when non-governmental organisations (NGOs) and politicians (who want to win votes for political power) bypass CWSA and provide water facilities to communities without following the laid down procedure. When this happens, no record is taken on the facilities to enable post construction supports (monitoring, supervising and technical assistance) be provided. Such facilities usually lack proper maintenance and are not sustained.

The engineer (RCWS 1) also said that rural water supply thrives mainly on loans, donations and grants from development partners. The government of Ghana also provides some funds for rural projects (water and sanitation including hygiene education). According to him, one challenge faced is when rural project funding is to come from the government of Ghana (i.e. GoG funding) since government has not provided the required budgeted fund for any rural projects. The engineer added that when GoG funds are provided they rather come so late.

With PV systems that use inverters for dc-ac, it has been revealed that dc-ac inverters are the weakest part that requires frequent replacement.

5.3 Results from the Study Conducted in the District Assembly

In the district assembly of the Agotime-Ziope district, interview was conducted for four senior personnel in charge of the administrative and developmental decision-making for the district. A face-to-face interview method was used based on various aspects of the water and energy supply issues in the district as already stated in chapter 3. Those interviewed were; the district chief executive (DCE 1), district coordinating director (DCD 2), district development planning officer (DDPO 3) and district engineer and chairman of the district water and sanitation development team (DWST) (DEng 4).

5.3.1 Results on Water Supply Facilities in the District

According to interviewee DEng 4, the National Water and Sanitation Programme (NWSP) in its decentralized form is carried out in the district as far as community water and sanitation

with hygiene practices are concerned. According to the district engineer, the policy guidelines for rural water supply in the district are to provide access to potable water and sanitation facilities in the district and to ensure the sustainability of those facilities. He stated:

“As the district engineer, and in pursuance of the NCWS programme, I play facilitation and co-ordination roles, and give technical assistance in terms of water facility options” (DEng 4)

However, the DWST is in charge of promoting community participation in rural water supply projects. This the district water and sanitation team does by organising community meetings at the district level and carrying out sensitization and mobilization programmes on water, sanitation and hygiene issues DEng 4 added.

He emphasized the role of women in the management, operation and maintenance of the water and sanitation facilities. He stated that women are involved in the point selection and also one-third of the management team is women. These are all contained in the NCWS Programme.

“The women’s capacity is enhanced through female leadership training (FLT) because most of them cannot read nor write. They are also trained in Management, Operation and Maintenance (MOM) of the facilities”. (DEng 4).

The study further showed that the level of community participation in rural water supply projects has not been very encouraging in recent times. This has been attributed to the fact that the community contribution of 5% of the project cost which also showed their commitment to the sustainable management of the facility was abolished by the government in 2009. This is how the interviewee put it:

“The cancellation of the community’s 5% contribution of the project cost or their labour by the government which the politicians now use as propaganda to discourage people in the communities from their full involvement in the project cycle has been one factor that is hindering effective community participation in rural water projects in the District” (DEng 4)

Again, it is in the scheme of the community water and sanitation programme that the district assembly, through the DWST, should give post construction support to beneficiary communities by monitoring the operation and maintenance of the facilities and also audit the system including financial management. Through participant observation, the researcher noted that although this is supposed to be done quarterly, hardly is it done because of inadequate logistical and human resource availability in the district assembly. Talking with the community development officers in the district, it was noted that these officers do not

have vehicles to convey them to distant communities except those they can reach on foot which are already close to the towns.

This observation made by the researcher was confirmed by the district development planning officer (DDPO 3) who, in a separate interview said:

“The district finances some of the projects but most projects are funded by government of Ghana and its development partners. However, for the past 3 years (2011-2013) the District Assembly has not been able to add any new water facilities to the existing ones. Furthermore, the District Assembly has not prioritized water as its major project. We think the Community Water and Sanitation Agency (CWSA) has to do it” (DDPO 3)

On the funding of the water facilities the response from the district chief executive (DCE) and the district coordinating director (DCD 2) is that the bulk of the funding comes from NGOs and Ghana Rural Water supply, this is how the DCE put it:

“Most boreholes are provided by Non-Governmental Organizations (NGOs) and these are most reliable sources. Ghana Rural Water supply is another donor, but this source is rarely reliable” (DCE 1)

On the sustainability of the systems, all the four interviewees said maintenance, operation and management of the water facilities rest with the respective community WATSAN committees and WSMTs.

Another reason the DWST chairman (Interviewee DEng 4) gave was that, communities are not managing their water facilities in a sustainable way because even though they make money out of the sale of water, their interest is in the amount of money they will save in the bank rather than the total functionality or maintenance of the system. In some communities, particularly Kpetoe and Akpokorpe, part of the revenue generated from the water tariff is used to support other development projects. This problem was mentioned by the secretary (KpWS 6) of the water and sanitation management team at Kpetoe and the regent (AkWS1) of Akpokorpe; they are reported later in this chapter.

Clearly, all these have serious implications for the sustainable management of these facilities in the communities. This may be one of the reasons why a lot of boreholes fitted with hand pumps were dysfunctional some of which are tabulated in Appendix VI. Confirming this, it was stated by interviewee DDPO 3, that they have not got to a point where communities were able to pay for services rendered to them fully. So a lot of facilities the researcher observed got broken down, thus, boreholes with hand pumps now lie in the bush not functioning.

5.3.2 Results on Power for Water Supply in the District

The study revealed that power supply for water delivery is another concern in the district. Although the grid has been connected to major towns in the district, most rural communities are still grappling with power supply issues. What is more worrying is the shortfall in the national power supply that led to power outages with its resulting load shedding exercise in the country reported in chapter 2. Apart from the national grid, the district has virtually no use of renewable energy except in one location where one single panel solar PV water facility (145 W) could be found. An interviewee who said he would prefer solar PV as power to be used explained his reason that:

“The communities pay commercial rate for the use of grid power to water supply systems which makes the cost of water production higher than that pertains in the urban centres. So the communities pay higher tariffs per month than urban centres” (DEng 4).

The respondent (DEng 4), revealed from the study, that for the sustainability of community rural water systems in the district the Government should assist communities to pay domestic rate for power used in water production or water supply so that there will be enough revenue reserve at the community level for maintenance and replacement of worn out parts of their water facility. This suggestion comes against the background that currently the communities pay commercial rate for power supply to water system since there is no government assistance and most of the revenue goes into payment of high energy tariffs.

The interviewee DCD 2 during the interview suggested that a pilot solar PV system should be installed in the district so as to create awareness about the technology in the district. He said:

“Using solar energy as power source may work well for the district because it is more reliable and the sunshine is abundant in Ghana. I saw application of solar PV water system in Lume Avete in the Akatsi district which was my previous station but did not see one in the Agotime-Ziope district. One main reason I think solar energy is not used in this my new district is lack of awareness about the technology in the district. I think if a pilot solar PV project is undertaken in the district, it would create the awareness about the system” (DCD 2).

At the end of the interview with the DCE1 he said:

“Solar energy is economical and so I am appealing for more boreholes to be drilled and some of the existing boreholes be supplied with solar photovoltaic systems in my district” (DCE 1).

5.3.3 Results from Structured Observation

In order to study the conditions of the available water facilities in the study area, thirty-five communities out of about 100 were sampled. The researcher divided the district into three zones; upper (Agotime/Kpetoe), lower (Ziope) and middle (in-between Kpetoe and Ziope). The communities were then randomly selected for structured observation. The water facilities were observed to ascertain the functionality of them; the results are presented in Appendix VI.

From the appendix, the type of water facilities and sources of water have been indicated. In addition, the conditions of the facilities are also stated as functional (F) or not functional (NF). Some of the communities have to depend on others for their water supply as such communities do not have any water facilities. For instance, four communities (serial numbers 4 -7 in the appendix) have to depend on Sarakope (serial number 3) for water supply from dam and stream.

It can also be seen from the Appendix that only one community (Hododokope serial number 9) has single panel (165 watts) PV system in the study area; it was dysfunctional. This system is one of the PVs supplied by COCOBOD reported in chapters 2 and 7.

The next section presents the results from the seven selected cases.

5.4 Case Studies in Agotime-Ziope District

Results obtained from the seven cases have been presented under this section in the following sub headings.

5.4.1 Case I Kpetoe

Within Kpetoe, the interview was conducted for the water and sanitation management team referred to as water and sanitation development board (WSDB), and the women group.

Those interviewed separately were the board's chairman (KpWB 5) and secretary (KpWB 6); area mechanic (KpWB 7); the senior mechanic/pumping station attendant (interviewee KpWB 8); the accountant (KpWB 9) and water tariff collector (KpWB 10) at the revenue office of the WSDB and water seller (KpWB 11). The same face-to-face method used at the district assembly for DEC 1, DCD 2, DDPO 3 and DEng 4 was used for these other (WSDB) interviewees.

The women group was the next interviewed. The same procedure was used for group and community interviews in each community. The people seated in a circle while the researcher, holding the audio recorder and the interview guide asked the questions and moderated the process so as not to allow any one particular person alone to respond to the questions. The assistants were taking down notes to help during transcription of the recorded interview. Almost all the interviews were audio and video recorded. Each interview took 45 – 60 minutes.

Between two and four trained research assistants helped the researcher in the data collection on each field visit. They helped in taking photographs, audio recording and notes while the interview was conducted by the researcher. During community meetings and group interview sections, the researcher went around the interviewees holding the audio recorder in his hand as he conducted the interview. Recorded interviews were later transcribed at home by the researcher. This was how all the interviews were conducted for this current research.

5.4.1.2 Demography of Kpetoe

Kpetoe, the district capital of the Agotime-Ziope district has a population 6797 (GSS, 2014). The indigenous people are traditionally Dangmes who migrated from Ada areas to their present location. These people are referred to as “Agotimewo”. Intermingled in the Agotime people are some Ewe speaking and other ethnic groups from Togo including Andos (Kables) and Hausas.

Kente weaving and farming are their major occupations. Figure 5.1 shows some samples of typical kente cloths from the district. The chiefs and people of the Agotime celebrate their annual Agbamevorza (literally meaning “Kente-festival”) in the month of September. This celebration is to bring citizens home from other parts of the country and Togo, friends and politicians to socialise and raise funds for development projects of the Agotimes especially Kpetoe.

Settlers from northern Togo resident in Kpetoe who are called the Kables, prepare local drinks from sorghum and millet called *solom* and *pito* while some of them sell *Awusa koko* which is local porridge. Large volume of water is used to prepare these drinks and porridge. Some of the people also do petty trading.

5.4.1.3 Water and Energy Supply Issues in Kpetoe

The river Tordze that runs through the town is the main source of water supply in Kpetoe. The researcher noted that the town has its own water pumping station which supplies potable water to the people through piped system under gravity flow. The management board has revenue office for its operations.

Water and sanitation issues in the town are managed by eleven members of the Water and Sanitation Development Board (8 men and 3 women). Seven are statutory members with four assembly members (representatives of each zone of the town at the district assembly) representing each of the four zones in the town. The expertise of members, as mentioned by the chairman (interviewee KpWB 5) are retired water works personnel, teacher, and other workers who underwent training in operation and management of water facilities.

According to the board chairman the board oversees all activities pertaining to management, operation and maintenance of the water system. Concerning major water related function of the board, he stated:

“The board’s major function is budgeting, planning, execution of plans and projects management and supervision as well as monitoring” (KpWB 5)

The board engages 5 permanent employees and 32 casual staff as point source water sellers stationed at designated selling standpoints in the town. The permanent workers are paid monthly salaries while the casual sellers are paid 10% commission on sales. Two pump attendants look after the water abstraction from the main river Tordze, treatment and storage. Extension of water pipelines to the town and to the homes of domestic (private) water sellers is carried out by the pump attendants who are also the mechanics in charge of all mechanical and sewer works. This was said by KpWB 8. Water bill distribution and collection of tariffs from water users (whose facilities are metered) are carried out by some of the permanent employees who are revenue collectors. The Accountant prepares the accounts of the books and work on the salaries, commissions and payments of external bills such as grid power bills. All payments and settlement of bills are made from the revenues generated from the water tariffs and water sales made.

The main and only source of power for water supply is the grid. However, electricity connectivity is frequently interrupted and power supply becomes erratic. As a result, the only water supply station does not deliver regular supply of water to every part of the town. This

situation is further worsened by the national load shedding exercise (explained earlier in chapter 2) and lack of power supply back up; hence, the inhabitants sometimes do not get water for weeks from the supply station. When this happens (in every month) the people use river Tordze directly. In the absence of treated pipe-borne water, the untreated water from the river is sometimes boiled before drinking else it is used without any form of treatment.

5.4.1.4 Results from the main Kpetoe town including Women Group

Table 5.1 shows a summary of responses of the women group in Kpetoe on household strength and water usage. According to the group of 72 women, the average household strength (number of people in a household) is 5.6 and average volume of water use per capita per day is almost 2 (i. e.1.9) of an 18-litre bucket or (34.2 litres). Each person was to state the number in her household and the quantity of water used per day; it was from this information the table 5.1 was generated. The average number of people per household of 5.6 is slightly higher than the figure quoted in the 2010 Population and Housing Census of GSS, 2014b.

Although the information provided in the tables in this section is quantitative data, it is presented in this chapter to aid and facilitate the discussions.

Table 5.1: Use of Water and Household Strength at Kpetoe (One bucket of water is 18 litres and figures in bracket are litres)

Number of respondents	Number of buckets used per /day	Average number of buckets per household/day	Number of people in households	Average number of people in a household	Average number of buckets per capita/day
72	760 (13680)	10.6 (190)	400	5.6	1.9 (34.2)

From the focus group discussion (FGD), in-depth interviews conducted with key players and observations made on the field, the study revealed that all is not well with the people in terms of potable water access. However the opposite picture has been painted by the chairman of the water and sanitation development board to show that everything needed is being done by the board. During the interview with the women group, they said the WSDB does not render the expected services to the people and this brought about distortions and dissatisfaction among the inhabitants of the town. When the group was asked about how the water system is managed and who is responsible for overseeing the process, one said:

“We do not know how the system is managed, but the WSDB members must know, they collect tariff but we do not know how it is used. For so many years now, they have not rendered account to us” (KpWG 12).

About management, operation and maintenance of the water system, the WSM board chairman said the board exercises direct management on the system. This includes involvement of the community in the initial stage of selecting facility option (siting and construction of the facility), management, operation and maintenance of the facility.

In response to another question as to whether there has been any problem with potable water access, this is what the group said:

“There has always been problem of us not getting water. If the grid power is not provided, we know it might come from the national grid. But very often we do not get water even when the grid power is provided in the town, so it is only the water and sanitation management board that can tell the problems they have” (KpWG 13).

The women said the management board does not call annual meeting to discuss issues relating to the provision of potable water and management of the water system to the inhabitants and that, it could take about four years of not rendering account to the people. Management board also feels the people do not attend meeting when they are called to such meetings hence there is lack of confidence in the management board.

When the chairman was asked “Does the WSDB regularly render accounts to the community; and if yes, how often”? This was his response:

“Yes, At least once a year” (KpWS 5).

It was therefore necessary to confirm or refute this assertion from the secretary. When he was interviewed 3 days later, he (interviewee KpWB 6) stated that when community meetings are called, people do not turn out and so for about 2 or 3 years the board did not render account to the people.

According to revenue collector (interviewee KpWB 10), private vendors who buy water from the WSDB to sell and individuals whose homes water pipes have been extended also refuse to pay water tariff regularly and this affects revenue generation. Concerning revenue collection, the pump mechanic was asked how effective revenue/tariff collection was; he said:

“Sometimes it is difficult, and so we disconnect the defaulters” (KpWB 8). This means the access to water is disconnected for those who default in paying their tariff until they settle

their indebtedness. In such case, the defaulter will also pay some penalty fee for reconnection. According to the revenue collector (KpWB 10), the private vendors complain that the board is only interested in money without providing them adequate water. Problem with revenue mobilization obviously has implications for sustainable water supply and system sustainability.

From the interview conducted with the board secretary (KpWB 6) and the Accountant (KpWB 9), it was revealed that expenditure items were many and the cost involved was also very high. These include utility tariff for power supply, cost of water treatment materials (filtration sand, chlorine, alum), salaries for permanent workers, allowances for board members, commission for temporary staff who sell water at stand pipes, cost of repairs and replacement of worn out parts. In addition, the board secretary (KpWB 6) said that part of the revenue generated from the sale of the water is donated towards town development, for instance, in organizing the people's annual traditional festival called "Agbamevor za". With these numerous cost elements coupled with poor revenue mobilization, expansion of the water system (apart from the problem of unsustainability mentioned earlier) may be difficult. The seriousness of water problem is such that even the board secretary himself said he was not getting potable water from the pump but relied on water from the river Tordze which he has been using to cook for pupils in his private school as was stated earlier. According to the secretary, he buys water from truck pushers and other water vendors who collect water from the river for business. Senior High students in the town also collect water from the river during acute water shortage usually in the dry season and when the pump did not function. Figure 5.1 shows some of the students collecting water from the river under a bridge as observed on one of the field visits to Kpetoe. During interview with some of these students, they said they drink the water without treating it. The situation is a bit better during rainy season when they harvest rain water using roof gutters or buy it from those who have traditional rain water harvesting systems.



Figure 5.1: Students collecting water from river Todze at Kpetoe



Figure 5.2: Truck and tricycle vendors collecting water from river Tordze

Sometimes during severe rainy seasons, the bridge seen in the figure 5.1 gets flooded even to the top but the water management board has not shown any attempt of building a dam to store excess water during the flood periods for future use.

5.4.1.5 Water Quality in Kpetoe

As stated in section 3.7.3, water quality analysis was carried out as one of the experimental methods used. After interviewing local people in the district on the quality of water from dams, ponds and river Tordze, it was clear that quality issues needed to be investigated. Even after installing the PV water facility at Kpota, (reported in chapter 6), patronage of the system by the community was monitored for almost 4 months from December 2014 to March, 2015 and was found to be low. The low patronage necessitated a probe into the usage of the facility. Again, poor water quality issues arose and so in March 2015, water quality analysis was conducted. The results for each community- Kpetoe, Ziope, Akpokorpe and Kpota can be seen in Tables 5.2, 5.4, 5.5 and 5.7 respectively.

The quality control department of the Ghana Water Company Limited (GWCL) - the urban water supply company in Ghana was engaged to carry out the water quality test on samples of the main sources of water in the case study communities. The regional director of GWCL was contacted and he allowed two of his laboratory staff at the quality control department to do the test. The two took their testing apparatus, (also dressed in their white overalls being identifiable to the villagers), as I drove them to the communities: Kpetoe, Ziope, Akpokorpe, Kpota and Mangoase (had dry pond and dysfunctional hand pumps so no water was sampled).

For samples from sources such as rivers, dams and ponds a sampler in a form of bottle (clean and sterilized) was used to fetch the water. With mechanized boreholes, taps were sterilized using burning flame (fire from cotton wool containing methylated spirit) after which water was allowed to flow for few minutes before samples were taken into the bottles. Water quality parameters such as pH, colour and turbidity were examined on the field; the pH was determined with a portable pH meter or Lovibond comparator with its corresponding pH disc. Colour: Colorimeter or Lovibond Nessleriser with colour disc. Turbidity: Turbidimeter. A 5 number universal bottle containing 10ml each of MacConkey broth solution was inoculated with 10ml of sample each for bacteriological examination.

On the day of sampling, samples were kept in an ice chest because it was a returned journey. The rest of the physical, chemical and the continuation of the bacteriological parameters were examined in the laboratory at GWCL. Spectrophotometer, conductivity/TDS meters and titration methods were employed to analyse the physical and chemical parameters. In using

the HACH Spectrophotometer, there is a corresponding reagent powdered pillow used to prepare the sample depending on the parameter being determined. After few weeks the results were given to the researcher.

Results from these tests on sample of river Tordze at Kpetoe are presented in Table 5.2

Table 5.2: Water Quality of River Tordze at Kpetoe

BACTERIOLOGICAL ANALYSIS				RESULTS
PARAMETER	TEST METHOD	UNIT*	WHO GUIDELINE VALUE	KPETOE RIVER TORDZE
Total Coli-form	Multiple Tube	MPN/100	0	>16
Fecal Coli-form	Multiple Tube	MPN/100	0	>16
E. Coli	Multiple Tube	MPN/100	0	>16
PARAMETER	PHYSICO-CHEMICAL ANALYSIS			
Turbidity	Absorptometric	NTU	0-5	37
Total Iron	FerroVer	mg/l	0-0.3	1.25

- MPN/100 = Most Probable Number per 100 milligram of water; mg/l = milligram/litre

As can be seen in table 5.3, it has been shown from the physico-chemical analysis that the turbidity value of 37 and the total iron content value of 1.25 in the river are both far above their respective range values of 0-5 and 0-0.3 specified by the World Health Organisation (WHO). Turbidity describes the amount of suspended impurities in the water; thus, water is said to be turbid when it contains visible materials in suspension and these materials are inorganic matter like silt, clay etc. With this high turbidity, it is clear that the water needs to be filtered; however, this is not usually the practice with some of the people in the area. During rainy season, due to turbulence of the running of the river, the turbidity level becomes so high that it costs the water board huge sums of money to desilt the water during treatment processes. This information was disclosed by the accountant (KpWB 9) and confirmed by the senior pump mechanic (KpWB 8) at the pumping station. Clearly, drinking this water with very high suspended impurities without appropriate treatment will no doubt put the victims at health risk. The quality of river Tordze found under the given test condition is inferior and must not be used for domestic purposes except for menial uses such as flushing out water closets. The turbidity needs to be removed after which the water must be disinfected to make it hygienic. To address the high iron and manganese content, the water needs to be treated by

the method of aeration which is exposing it to atmospheric air for oxidation to take place so as to remove iron and manganese which precipitate as iron and manganese oxides.

What is of greater concern is that, all the values obtained from the bacteriological analysis for total Coliform, faecal coliform and *Escherichia coli* (*E. Coliform*) are all above the acceptable WHO's value of zero. For each of these parameters, the test result showed a value greater than 16.

5.4.1.6 Solar Energy Use in Kpetoe

During the interview with the women group, they were not happy about their present power system used for their water supply. This is how it was stated:

“We do not think there is anything good about our power system. Because even when the system is working there are certain parts of the town that do not get water the weakness with the power supply is that the “Dumsor” situation has worsened our water supply condition” (KpWG 12)

(“Dumsor” is a Ghanaian language meaning “switch off and on” referring to the 24 hour load shedding exercise in Ghana).

The women stated that one of the ways of solving their potable water supply problem is to either tap water from urban water supply in Ho which is about 20 km away from Kpetoe or they should explore the possibility of solar energy since the sunshine is free of charge and is constant and regular in supply. Their reason stated is that by using solar energy, they will not pay power tariff and water bill too will reduce because the water supply station will also not pay any utility bill. When a question was put across during the interview in order to probe further if really they knew of the PV technology this is what the women said:

“We think solar may be better, because in your opening statement, you mentioned that you are studying on rural water supply using solar energy, so we need solar because for that we will not be paying for electricity tariff and our water bill too will be less. We think solar is always there except in the night. But you can also advise us as to what to do” (KpWG 13)

The board chairman had earlier in a separate interview, stated that he did not know if he would prefer the use of solar energy to the grid because the choice of option will depend on cost effectiveness and reliability. *“Choice of energy option will depend on cost effectiveness and reliability”* (KpWB 5)

Lack of awareness about the solar PV technology in Kpetoe has been shown among the people except the student respondents who demonstrated some awareness about the technology. It also implies that the capacity for the technology is not available in the

community as already said by the DDPO 3. This clearly is a factor that militates against the adoption of the solar PV for water pumping in this community.

5.4.2 Case II –Ziope

Ziope is the second case considered in the result presentation because the water and energy situation is similar to that of Kpetoe.

5.4.2.1 Results on Demography of Ziope

Ziope is the second largest town in the district with a population of 2194 people (GSS, 2014). The people of Ziope are mostly settlers from other places such as Aborlove/Norlopi, Atiavi of the southern part of the Volta region. Some of the people are also settlers from Togo.

The main occupation of the people is farming. Available crops cultivated are tomatoes, groundnut, maize, cassava, beans, okro and pepper. Some of the people especially men are also kente weavers and others engage in petty trading just as it is in Kpetoe. The chiefs and people of Ziope with the surrounding villages celebrate their annual Agbleza (literally meaning “farm-festival”) in the last week of August. This celebration is to bring citizens home from other parts of the country and Togo to socialise and raise funds for development projects.

5.4.2.2 Water and Energy Supply Issues in Ziope

The chief, water and sanitation (WATSAN) committee and women group of Ziope were the participants for the study. There is one artificial dam (pond), boreholes and hand dug wells in the town as sources of water for the people. The town does not have its own water supply station as it is in Kpetoe; but the pumping station is owned by an NGO. The NGO abstracts and treats water from the community’s artificial dam and sells same to the people at a negotiated price. The pond (artificial dam) was constructed in 1965 and it is at the outskirts of the town (about 1 km away) where the community draws water from. Three boreholes were sunk but the water in two of them is not good for human consumption. The people also harvest rain water during the rainy season, but not necessarily for sale except some people who commercialised their harvested rainwater.

Currently, the NGO supplies clean water to the community at a fee. It has two selling points in the town. The chief and people of Ziope have signed a memorandum of understanding with the NGO for the company to produce potable water and sell to the people at agreed price. It is a 15 year contract agreement. The principle being adopted is build operate and transfer

(BOT). Thus, at the end of the agreed period, the water supply station will be transferred to the chiefs and people of Ziope and not to any private operator this was revealed during the interview with the WATSAN chairman (ZpWS 1) and later with the NGO's business executive officer (ZpWS 2).

From the business executive officer, the NGO has 26 of such stations in Ghana and he goes round to monitor the work of pumping station attendants in the Volta region. According to him, the initial agreement was 10 years and the cost of water per 18-litre bucket was twenty Ghana pesewas (GHC 0.20). This price was considered too high so it was reduced to GHC 0.15 and the contract duration was increased to 15 years. (For easy conversion, 1 USD = GHC 3.00 =300p). This information was later confirmed by the Water and Sanitation (WATSAN) committee chairman (ZpWS 1). The business executive officer further added that it was very difficult to break even because of the expenditure items they needed to take care of. These include electricity tariff, station attendant's salary, high treatment cost especially during rainy season when the turbidity of the water source is very high because it becomes muddy ((just as reported about Kpetoe). According to the officer, while cost of expenditure goes high during rainy season, the sale of water at the same period falls drastically as many people harvest rainwater.



Figure 5.3a: Ziope water supply station

Meanwhile the NGO buys its spare parts from India and America. This may have adverse implications for Ziope when the system is finally transferred to the town. Figure 5.3 illustrates the pumping station and the dam.

There is a 9 member water and sanitation (WATSAN) committee, (two of them are women) whose chairman doubles as the chairman of the joint committee of the town and the NGO. Before the NGO came into the town, the committee used to oversee all activities pertaining to management, operation and maintenance of water and sanitation systems. The chairman deputises for the paramount chief of the town in almost all matters since the chief does not reside in the Ziope town. The NGO renders account to the WATSAN committee annually as stipulated in the MOU. The Water and Sanitation Committee (WATSAN) works on behalf of the chiefs in the day-to-day operations of the NGO. The committee supervises the operation and serves as the link between the community and the company but nobody from the town understudies the NGO in its technical operations so that when the water supply station is later transferred to the town it can conveniently manage and operate the system technically.

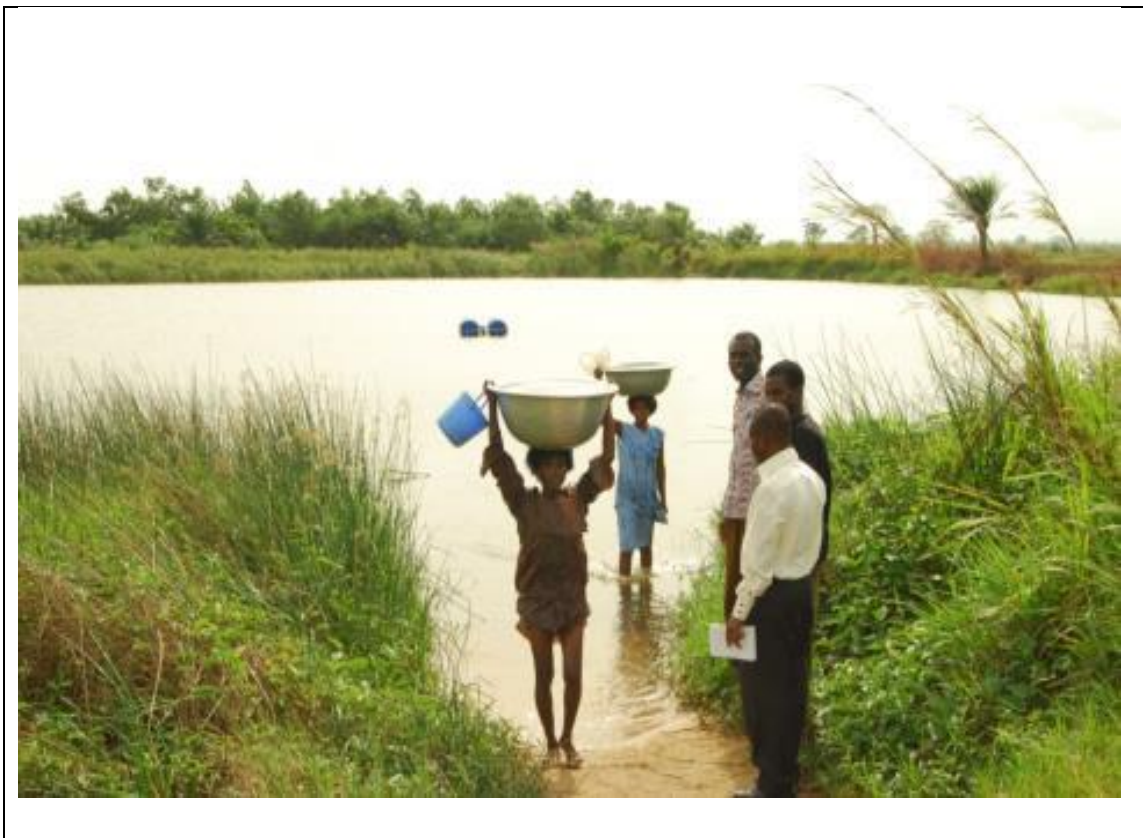


Figure 5.3b Ziope dam with research team

Ziope is connected to the grid which supplies power to it and few of its numerous surrounding communities. The NGO relies on the grid for its power supply. However, electricity connectivity is usually interrupted and power supply becomes erratic. When this happens, a diesel generator is used but this is more expensive to run. For instance on one occasion, as the researcher was told by the production manager (Interviewee ZpWS 3), diesel worth GH¢ 50.00 (about 17 USD in 2014) was used to run the generator for one day, but a sale of only GH¢ 15.00 (5 USD) worth of water was made.

5.4.2.3 Results from the Women Group in Ziope

As done in, and reported about Kpetoe, the same was done with the women group at Ziope.

Table 5.3: Use of Water and Household Strength at Ziope (One bucket of water is 18 litres and figures in bracket are litres)

Number of respondents	Number of buckets used /day	Average number of buckets used per household/day	Number of people in households	Average number of people in a household	Average number of buckets used per capita/day
44	408 (7344)	9.2 (165.6)	213	4.8	1.9 (34.2)

Table 5.3 shows a summary of responses of the women group in Ziope on household strength and water usage. From the FGD, the study revealed that the average household strength (number of people in a household) is 4.8 and average volume of water used per capita per day is about two buckets (i. e. 1.9 of an 18-litre bucket or 34.2 litres). In the past when the unimproved water source was being used by the people, water consumption per capita per day, mentioned by the group was one bucket (18 litre) on the average. Water was then collected directly from the dam and it was free of charge. But with the improved system, consumption has doubled even though the people have to pay for it. The study further revealed that the people scarcely use the water from the borehole because it is not too good, so patronage is poor, but the people depend on hand dug well. The resource from hand dug well is for menial washing because it is hard and does not lather easily with soap. The treated water which is sold by the NGO is used for all purposes (drinking, washing and bathing). Those closed to the dam, collect water directly from the dam for washing and bathing. During dry season, people buy untreated dam water from local vendors (truck-pushers).

The cost of water is said to be very high. While a bucket of water (18 litre) sold by the NGO is GH¢ 0.15, that from the well sells at GH¢ 0.10 and rain harvested water is sold at GH¢ 0.30 per bucket. Dam water sold by truck-pushers (vendors who collect water from the dam in special plastic containers, i.e. 27 litre containers packed on a truck) as seen in figure 5.2 are relatively expensive according to the women. Water in three of such containers sells at GH¢ 2.50. The group hinted that they would have preferred the cost is brought down to GH¢ 1.00.

5.4.2.4 Water Quality of Dam at Ziope

As can be seen in table 5.4, a physico-chemical analysis of sample of the dam water revealed a turbidity value of 7 and the total iron content value of 0.46. Both values are above their respective range values of 0-5 and 0-0.3 specified by the World Health Organisation (WHO). With high turbidity value of 7 instead of World Health Organisation's maximum value of 5, and iron content in excess of 0.16 above the WHO's maximum value is 0.3, the water needs to be treated as described earlier for Kpetoe.

Table 5.4: Water Quality of dam Water at Ziope

PARAMETER	BACTERIOLOGICAL ANALYSIS			RESULTS ZIOPE DAM
	TEST METHOD	UNIT	WHO GUIDELINE VALUE	
Total Coli-form	Multiple Tube	MPN/100	0	>16
Faecal Coli-form	Multiple Tube	MPN/100	0	>16
E. Coli	Multiple Tube	MPN/100	0	>16
PARAMETER	PHYSICO-CHEMICAL ANALYSIS			
Turbidity	Absorptometric	NTU	0-5	7.0
Total Iron	FerroVer	mg/l	0-0.3	0.46

5.4.2.5 Solar Energy Use in Ziope

The study revealed through the FGD that there is no solar water pumping system in Ziope. Furthermore, the group said they have neither seen nor heard about solar water pumping system. This is how it was stated: *"Solar energy use for water pumping is not known to us, we do not know how it works"*.

However, the WATSAN chairman who seemed to have an idea about the technology said he thinks the use of solar energy will be cheaper than the grid as the sun is free of charge. He said:

“In my opinion solar energy may be cheaper than electricity from the grid because the sun is natural and it is free. Also the electricity company charges the NGO that sells water to us at commercial rates leading to high water tariff. As a result, the organisation transfers this high cost to the people in the community by selling the water at relatively high prices in order to meet their high operational and overhead costs”- (ZpWS 1).

Another reason the chairman gave in preference of solar energy to the grid was that, the power supply from the grid has not been stable but erratic (i.e. frequent power outages from the grid); and that tariff for solar power is not likely to be at commercial rate. This was corroborated by the women group. They said that for the treated dam water supplied by the NGO, once there is grid power they get water which is clean and hygienic. But the 24 hour power ration or load shedding in Ghana is what has not been favourable to them.

An additional weakness disclosed in the water supply situation by the group is the fact that they buy rain harvested water which sometimes is found with dead reptiles like lizard; and that people who collect water from the open dam walk into it sometimes with sore on their legs and thus contaminate the water.

On how best they thought the weaknesses found in their water supply situation could be addressed, this is what the women group said:

“In the month of April, 2015 we were told by the WATSAN committee that the opportunity of getting urban water supply was being explored so if that works for us, it is only then our water situation can be better (ZpWG 4)

It is true that the urban water company is a public-private liability company with substantial government subsidy provided to cushion the Ghanaian populace; so it is cheaper than the water being sold by the private NGO. But the two companies use the same grid as source of power supply which both the WATSAN committee chairman and the group said has been unreliable. How is extension of urban water to Ziope going to solve the problem completely? This was a question they claimed they could not answer. Again by extending urban water to Ziope would be a contravention of Acts 564 that defines the category of communities that fall under rural locations of Ghana and the type of water and sanitation facility to be provided. The people of Ziope demonstrated no knowledge about PV system. They lack the education and technical expertise when it comes to solar PV technology. Awareness needs to be created, technical capacity to be built and financial schemes that would encourage the chiefs and people of Ziope to want to go into the use of solar water pumping system be considered. Grid connected solar PV system will be most suitable for the water supply needs of the town.

They have socio-economic and cultural factors that may positively influence the adoption of the PV system in the town as explained in chapter 8.

5.4.3 Case III- Akpokorpe

5.4.3.1 Demography of Akpokorpe Community

Akpokorpe is a community lying between Kpetoe and Ziope along the main Ho-Aflao trunk road having a population of 1,103 people and surrounded by over 10 smaller villages. Just like the people of Kpetoe, the indigenous people are traditionally Dangmes who migrated from Ada areas to their present location. They are also referred to as “Agotimewo” and have similar characteristics as already considered under Kpetoe.

The community is a farming one and people are basically subsistence farmers. Common crops cultivated are tomatoes, groundnut, maize, cassava, beans, okro and pepper. Some people are also kente weavers.

The community depends on only one grid powered mechanized borehole for their water supply needs. There is only one dam/pond in this village but it is always dry, therefore unlike the two other villages already considered (Kpetoe and Ziope), the people of Akpoko depend on the only mechanized borehole. Some homes have rainwater harvesting systems but not commercially operated except in dry season. The land is muddy and contains not-too-much ground water as the researcher was told by a consultant (borehole and pump engineer) who the researcher interviewed at the time he was seen repairing the broken pump in the Akpokorpe community (see Figure 5.3: Water collection at Akpokorpe by pupils and women (top) and repair of pump (bottom) by contractor with researcher (second right)).

5.4.3.2 Interview Results at Akpokorpe

The researcher first called on the Regent (AkpWS 1) of the head chief of the community during the initial exploratory study. Contact had been made and the essence of the research was explained to the chief and opinion leaders during the subsequent visits as was the practice with all other communities visited. There is an 8 member WATSAN committee with 3 women as members. Women were met at the water collecting point and the school pupils who were collecting water were also interviewed. Two women who were water sellers (AkpWS 3 and AkpWS 4) and the WATSAN committee secretary (AkpWS 2) were parts of the other participants. The water sellers, according to the information received from the regent (AkpWS 1) ran shift every week. This was to prevent suspected under declaration of

sale which occurred when only one person was engaged to sell the water because there was no water meter fixed to the system to be recording the volume of water pumped and sold.

Table 5.5: Water Quality of Akpokorpe Water

PARAMETER	BACTERIOLOGICAL ANALYSIS			RESULTS
	TEST METHOD	UNIT	WHO GUIDELINE VALUE	AKPOKORPE Borehole
Total Coli-form	Multiple Tube	MPN/100	0	0
Fecal Coli-form	Multiple Tube	MPN/100	0	0
E. Coli	Multiple Tube	MPN/100	0	0
PARAMETER	PHYSICO-CHEMICAL ANALYSIS			
Magnesium	Titrimetric	mg/l	0-50	72.9
Chloride	Argentometric titration	mg/l	250	260

From the interview with the regent (AkpWS 1), the practice in the Akpokorfe works well to the liking of both management (chiefs, WATSAN committee and the opinion leaders) and the community (women group and the school pupil about 35). The price of water per 18-litre bucket is the lowest in the district (i.e. GHC 0.05p) and water quality is also acceptable even though it contains slightly excess magnesium (22.9 mg/l) and chloride (10 mg/l) than the WHO's guideline values shown in table 5.5. Also there is no competitive alternative source of water so demand for water is always high. The community's major concern is inadequacy of the water supply. The chiefs and one opinion leader (AkpWS 2) through whose initiative the borehole at Akpokorpe was mechanized and whom the people seem to trust for their development projects) said they are exploring other options of which solar PV is one. The researcher was told that the water sellers promptly render accounts to the WATSAN committee on weekly basis and the committee also renders account to the town during annual Easter durbar. However, just as it is done at Kpetoe, part of the revenue generated from the water tariff is used for other development projects as the researcher was told by the regent (AkpWS 1) and confirmed by the water sellers (AkpW 3 and AkpW 4) and the development officer in the town.



Figure 5.3: Water collection at Akpokorpe by pupils and women (top) and repair of pump (bottom) by contractor with researcher (second right)

Also they pay high utility tariff for the use of the grid. For instance, in 2013, GH¢ 5,000.00 revenue was declared; and in 2014 when almost GH¢ 6,000.00 revenue was declared, about a third (GH¢ 1,700.00 = 566.67 USD) out of this amount was used to pay for the electricity alone. With 100% increment in tariff announced by the Public Utility Regulatory Commission (PURC) in 2015 the people in Akpokorpe will be paying more tariffs. In August

2015 the researcher observed at Akpokorpe the water facility being replaced with a new pump by the CEO of Agbey Engineering Company but not the area mechanic of the district. When the regent (acting chief; AkpWS 1) was asked what the problem was, he said the system broke down over a month ago, and it took them sometime to raise funds for the repairs.

Figure 5.4 shows on the top side, some women and school pupils collecting water from the mechanized borehole at Akpokorpe while on the bottom side, the damaged system is seen being repaired by the pump technician/contractor with the researcher (second right) bent down to observe. As stated in the case of Kpetoe, using part of the revenue generated from the water tariff for other development projects may put the facility at risk in terms of its sustainability.

5.4.4 Case study IV: Mangoase

5.4.4.1 Results on the Demography of Mangoase

Mangoase is a village about 5 km from Kpetoe and it is close to Togo at the north-east on the district map shown in chapter 3. The population of the people is about 80 (not shown on the 2010 population and housing document since the population is less than 450 people). They are mainly farmers but kente weaving is also their occupation.

The community had two nonfunctional boreholes at the time of the visit in February 2013; with one dry artificial dam (pond). Figure 5.5 illustrates some features and people of the community. From the top left to the bottom right, is the community with some of the inhabitants in photograph with the researcher, one of the two abandoned boreholes with GMIMII hand pump, dry dam with two women trying to collect some water and collected water from the muddy dam. This community does not have WATSAN committee so the researcher interviewed the head chief and some of the people (men, women and the youth) in the village numbering 23 people.

5.4.4.2 Interview Results

According to the chief of the village, the two boreholes were sunk by an NGO but not the district assembly. The borehole in the town seen in the figure 5.6 used to work for about two years and could no longer pump water. The second borehole which was sunk in the bush did not produce any water except the water pumped on the drilling day. The chief (Mang 1) said they made several attempts to have the district assembly come to repair the two boreholes but

there was no positive response from the assembly. According to the chief, another group of people wanting to establish church in the community assured them of water supply but no such facility was provided. The women said they suffer most because they have to travel about 2 km to access water. Although there is a community nearby called Agorhome with borehole water facility, the Mangoase community could not access water from Agorhome because there was a conflict between these two communities. No source of power supply was available although there was the possibility of grid extension to the community.

Water collected from the muddy water is left to settle after it has been treated with alum.



Figure 5.4: Mangoase community, abandoned borehole, dry dam with scooped water from dam

The community has basic (elementary) school up to class 6 (with pupils' ages ranging from 6 to 14 years) but no junior high school; so the pupils walk to and from school daily, a distance of about 5 km to Kpetoe the district capital.

5.4.5 Case V: Kporta

This is the community selected for further study based on the fact that the community's borehole was selected and mechanized with the solar PV system for the current study. Further details especially with regards to the PV installation and experimentation on the system are presented in chapter 7.

5.4.5.1 Location of the Community

From the district map shown in Figure 3.3: Agotime-Ziope District map with case study locations, Kporta is located in the south-eastern part of the Agotime-Ziope district, about 5km from Ziope and 35km from Ho which is the capital city of the Volta region of Ghana. The community is the biggest in that area surrounded by other smaller villages. These include Dadifedo, Aforkpui, Kortsrala, Bedzame, Hehenkor, Dorkorfe, and Tsavanya. The only basic (elementary) school in the area where children from the surrounding villages attend school is also located in this community.

5.4.5.2 Population and Occupation

The population of Kporta ranges between 200 and 300 people and for sizing and design of the PV pumping system (in chapter 6), an average population size of 250 people is used for the community in this thesis. According to the WATSAN chairman (KpoWS 1) he and his committee compiled a list of the people in the community two years earlier for the health workers. It was from the list he recalled the population of the people.

The inhabitants are basically farmers; they cultivate tomatoes, groundnut, maize, cassava, beans, okro and pepper. Some of the people, especially the men are also Kente weavers while the women prepare and trade in palm oil.

5.4.5.3 Water Supply Situation in Kporta

The water sources in the community are one borehole with NIRA hand pump (see figure 2.20) mounted on it, and one dug out pond ('dam'). However the pond (figure 5.6) water is contaminated and infested with water borne diseases including guinea-worm, and it dries up during the dry season (December-Mid-March). Until recently, most of the surrounding

communities depended on the only borehole in Kporta during the dry seasons for their water supply.

5.4.5.4 Water Supply Development in the Community

During the initial exploratory studies in the district which included Kporta, it was found that before the year 1970, the community used to collect water from a river after walking a distance of about 1.5 km. But in the early 1970s, the authorities of the then Ho district assembly (now Ho Municipal assembly) constructed the pond ('dam') for the Kporta community to lessen their problem of collecting water from the river. In the year 2005, the borehole in the community was constructed by the Adaklu-Anyigbe district assembly which was created from the Ho district in 2004. However, by the Legislative Instrument (LI 2080), the Agotime-Ziope District was established when the then Adaklu-Anyigbe district was split into two: Adaklu and Agotime-Ziope districts in June 2012 (GSS, 2014).

5.4.5.5 Qualitative Research Results from Kporta

Kporta being the main research community has been considered under both qualitative (in chapter 5) and quantitative (in chapter 6) studies. The results for the qualitative study are presented in this section.

The researcher and two of his assistants carried out the interview at Kporta. The procedure did not change. The people seated in a circle while the researcher, holding the audio recorder and the interview guide asked the questions and moderated the process so as not to allow any one particular person alone to respond to the questions. The assistants were taking down notes to help during transcription of the recorded interview.

5.4.5.6 History of Water Usage in Kporta

During the interview at community meeting, the researcher gathered that in the past (1970s) when the borehole was not constructed, the people relied on water from the pond (dam) for everything the community would need water to do: washing, bathing and drinking. But the quantity used per person on daily basis was just about one bucket (18-litre) and even less during the dry season. According to the elderly women present at the meeting, their water usage was worse in those days (i. e. before 1970s) when they trekked long distances (1 ½ km) to collect water from rivers.

The secretary (KpoWS 3) said, it was realized that the water from the pond was unhygienic that led to contracting of guinea worm disease by the people. In addition, the pond was

getting dry during the dry season (December-March) and this made the situation bad for the community.

The need to sink a borehole for the community arose, so the community sent a delegation to the district assembly for help. A feasibility study was carried out by the district and a site was located for the drilling of the borehole. As to how the borehole was made, the vice chairman (KpoWS 2) said:

“We held a meeting and informed our people that the district assembly willingly wanted to help with a borehole but we the community are to contribute three hundred million cedis (currently this is GHC 300.00. We levied every household depending on the size and raised the amount so the assembly constructed the borehole for us and fixed NIRA pump on it” (KpoWS 2).

Another person said, before the construction, a seven-member water and sanitation (WATSAN) committee was formed and trained by the District Assembly and CWSA so that they could manage, operate and maintain the facility. They were also trained in water treatment by method of filtration and boiling for drinking; the respondent added. Confirming this, the secretary said after their training, the WATSAN committee trainees on their return to the community also trained the people about how to filtrate the water. Therefore the community treated their pond water by means of boiling and filtration for drinking.

The vice chairman (KpoWS 2) added that when the borehole was finally constructed in 2005, the committee appointed a caretaker and water seller to be in charge. He further explained that during the dry season people from some of the surrounding villages came to Kporta to buy water pumped from the borehole. Account for the facility known as WATSAN committee account was opened with Ziope Rural Bank at Ziope in which revenue generated from the sale of water was kept; the chairman noted.

5.4.5.7 Current Water Usage in Kporta

Table 5.8 shows a summary of responses of the Kporta community on household strength and water usage. According to the 32 community people (18 females and 14 males) present at the meeting, the average household strength (number of people in a household) is 4.5 and average volume of water use per capita per day is almost 2 (i. e.1.87) of an 18-litre bucket (or 33.7 litres). Each person was to state the number in his/her household and the quantity of water used per day; it was from this information the table 5.6 was generated. This particular interview was carried out on 5th June, 2015 at the community centre of Kporta.

Table 5.6: Use of Water and Household Strength at Kporta (One bucket of water is 18 litres and figures in bracket are litres)

Number of respondents	Number of buckets used /day	Average number of buckets used per household/day	Number of people in households	Average number of people in a household	Average number of buckets per capita/day
32	271 (4878)	8.4 (151.2)	146	4.5	1.87 (33.7)

The people of Kporta mentioned that during dry season water collectors mounted long queues at the borehole site as each person waited for his or her turn to fetch water. This resulted into conflict situation usually leading to quarrels and breaking of good relations between people of the same family or communities.

5.4.5.8 Assessment of Impact of the PV System on the Community

Detailed design, installation and performance evaluation of the PV system have been captured in the following chapter 6. However part of the qualitative result has been considered in this section.

When the solar PV was installed, the water collecting point has been brought from the bush where the borehole has been sunk to the community using pipeline of 168 m long. With the water collection point now at the doorsteps of the people in the community itself, and the fact that the drudgery of using human strength in pumping water is curtailed with fixing tap of two spouts onto the PV system, there was the need to conduct some tests and observations to determine the impact of the new solar PV system on the community. Therefore, considered in this section is the assessment of the impact the PV system made on the people in the Kporta community and those other communities who come to fetch water during the dry season. The impact is considered in relation to water quality and availability or otherwise of alternative water sources.

5.4.5.8.1 Water quality at Kporta

Table 5.7: Water Quality of dam at Kporta

BACTERIOLOGICAL ANALYSIS				RESULTS OF ANALYSIS	
PARAMETER	TEST METHOD	UNIT	WHO GUIDELINE VALUE	KPORTA BOREHOLE	KPORTA DAM
Total Coli-form	Multiple Tube	MPN/100	0	2.2	>16
Fecal Coli-form	Multiple Tube	MPN/100	0	2.2	>16
E. Coli	Multiple Tube	MPN/100	0	0	>16
PARAMETER	PHYSICO-CHEMICAL ANALYSIS				
Turbidity	Absorptiometry	NTU	0 - 5	0.75	45
Total Iron	FerroVer	mg/l	0 - 0.3	0.08	3.21
Total Hardness	Titrimetric	mg/l	500	970	60
Total Dissolved solids	Electrometric	mg/l	1000	1915	107
Magnesium	Titrimetric	mg/l	0 - 50	218.7	7.3
Sulphate	SulfaVer 4	mg/l	0 - 250	600	0
Chloride	Argentometric titration	mg/i	250	604	20

Table 5.7 shows results of test conducted on water samples from the Kporta PV system and from the pond/dam. Evidently both the bacteriological and physiochemical results indicate that the water sources in the Kporta community failed to meet the drinking water standards. With the exception of E coli, turbidity and total iron contents, the PV water failed to meet the standard in all respects. From the sample tested, the result has shown that the PV system water is hard while the pond water is soft; each with hardness value of 970 and 60mg/l respectively against the WHO's standard value of 500 mg/l shown in the table 5.7. There are excessive magnesium, sulphate and chloride in the PV system water than they are in the water from the pond as shown in the table. Basing findings on the test result, both water sources have to be subjected to turbidity removal followed by disinfection as appropriate water treatment to make the water safe for drinking.

Hardness of Water: During the group interview, the Kporta people said because of the hardness of the water pumped by the PV system from the borehole, they use more soap in washing their clothing or for bathing, than when washing with the pond water. Confirming the test result, the people explained that the water from the pond (dam) is soft and so small amount of soap is used in washing and bathing with it. This observation also agrees with what has been reported by Gbedemah (2010).

High Salinity: The people further mentioned that, there is much salt in the water pumped from the borehole with the PV than that in the pond. This confirms the people's claim that the borehole water is salty while the pond water is tasty. Because of the saltiness of the water, some people including the school pupil still drink water from the dam. One respondent who lives in the city but came home (Kporta) for 2014/2015 Christmas/New year festivities said:

"I am a native of Kporta resident in Accra (capital of Ghana), I came to my parents for the Christmas and New Year festivities. When I arrived in the town and saw that our borehole was mechanized with the solar PV, I was happy because it was a dream came true. But my worry is that when I drink the water, I suffer from running stomach because of its salty nature. I am used to drinking urban treated water; I therefore resort to using the dam water for washing and drinking. I boil it and after I allow it to cool, it is stored for drinking. The only thing I use the PV water for is cooking. If you can do something about the salty nature, we can use it for everything because the solar PV water system is closer to us than the dam water. We would love it the more, if something can be done about the high salt content." (KpCm 1)

Cost of PV water: The community people said even though the pond (dam) is farther away from the town (about 20) minutes' walk, the water is free for everyone to fetch but the PV water is paid for. The secretary to the water and sanitation management team explained that the cost per se, is not the main reason why some people still go to collect water from the pond because the price for one bucket is GHC 0.10p which to them is manageable. He said it is rather the quality that is the main issue with the PV system water.

This attitude towards the PV system by some of the people is not surprising because, during the commissioning of the system, the District Chief Executive explicitly mentioned it in his address to the people. He said:

"Do not abandon the solar system and collect water from the dam which is infested with pathogen to the detriment of your health. This is how the people of my home village abandon the borehole we have and they go to fetch water from the river and the stream in order that they would not pay for it. Your solar system is very expensive and it will need much money for repairs when the need arises. Rev. Dzokoto(Researcher) who brought this expensive technology to you as his research project should not be expected to come and repair it for you"(DCE 1).

During the field study, it was observed that in any community where there is alternative water source available (Kpetoe, Kporta, Aforkpui and Ziope), which is usually pond, river or hand dug well, some of the people in the community still collect water from those sources even though they are untreated and unhygienic. Just around March, 2015 when an NGO sunk a borehole at Aforkpui also in the case study area, the community still collects water from their

pond and abandons the borehole with a hand pump; based on the quality of the water. Similar findings have been reported by Limantol (2009) and Gbedemah (2010).

5.4.5.9 Pattern of Water Collection from the System

The current water usage situation found at the Kporta community raises a lot of policy concerns. Most of the inhabitants in the community demonstrated some kind of preference they have for the water being used for their domestic purposes. As reported by Engel et al, 2005, household water source and usage patterns vary considerably based on changes in accessibility of alternatives and quality considerations for different uses (Engel et al, 2005). Obviously, the inhabitants demonstrated that even with the provision of the solar PV water system which has brought the water point to the door steps of them and lessens the drudgery of using human strength in pumping water, many households including the school pupils (most of who come from the surrounding villages) continued to use water from the pond which is unsafe to human health. This attitude of the people in the community undermined the initial education given to them on the need to resort to the water from the PV system as that is more hygienic than the water from the pond. The education given to the people was in line with the guidelines of the Community Water and Sanitation Agency (CWSA). It was given by a team comprising the researcher, Community Development Officers, and the District Water and Sanitation Team of the Agotime-Ziope district and was reiterated by the District Chief Executive before he commissioned the facility.

5.5 Cases Outside the Study Area

Two communities which are outside the case study area have also been included in the case studies because they already have the solar PV water systems in use. It was assumed that some lessons could be learned from them to be adapted or avoided in the current research.

Lume Avete in the Akatsi South district and Adaklu Anfoe in the Adaklu district are the two observed communities which have been using the solar PV water system since 1998/99.

5.5.1 Case VI: Lume Avete

5.5.1.1 Demography of Lume Avete

Lume Avete is in Akatsi south district and has a population of 1055 members. Major occupation of the people is farming. Some of the women do petty trading in the agriculture produce. Some are also food vendors including palm oil preparation which requires the use of large volume of water. Lume Avete has a basic school (elementary) that serves the people

and those living around surrounding villages, in giving formal education their children. The community is currently connected to the grid. Before the grid connection, the people has been using the solar PV water pumping system donated to them by the Danish International Development Agency (DANIDA). However, the PV system is still operated as stand-alone even after the grid connection. Figure 5.5 shows the PV system seen at Lume Avete with the research team and system attendant.



Figure 5.5: PV water system at Lume Avete with research team and system attendant

5.5.1.2 Description of Method of interview

During the initial exploratory studies when the researcher contacted the Volta regional office of the Community Water and Sanitation Agency, the monitory officer in the course of the interview informed the researcher that the solar PV systems were installed in some communities in the region including Lume Avete and Adaklu Anfoe. On the 22nd March, 2013, the team first visited Lume Avete for the officer to officially introduce the researcher to the people in this community.

The PV system attendant (LumWS 1) conducted the research team round the facility. Official contact was made on that day but the WATSAN committee chairman had then travelled outside the town. The researcher continued to visit the village, sometimes on his way to his hometown.

Two official visits for the purpose of the research were made as follow ups to the first. These visits were used to arrange for the main interview since the community must be informed and a date agreed upon. The contact person between the community and the researcher is a key WATSAN committee member (LumWS 2). Communication existed between the two until a date for the interview was fixed and all the arrangements made for a successful interview.

On 31st March 2015, the research team (researcher and three assistants) went to the community to interview the people on the PV system impact assessment. The team got to the village at 8:30 am, 30 minutes ahead of the scheduled time. A gongor beater (town crier) went round announcing the team's arrival for the people to come out for the meeting. It was until 9:30 am before everybody who was attending the meeting settled. At 9:35 am traditional exchange of greetings, introduction of participants and the team members, and Christian prayer (upon their own request) was said by one of the women leaders (LumWS 3) from the community. The interview lasted for one hour and five minutes.

To start with the interview, the researcher read the questions in English as they were on the interview guide but interpreted it to the people in the local language. Relevant instructions were given to the people and some key terminologies such as "household" were explained to them. For instance, people of the same household were those under the care of the same family head present in the home (i.e. husband, wife, children/dependents all of who are living together and are catered for by the same family head). It was indicated from the people that everybody understood each of the questions.

While the researcher was asking the questions and directing the people, one assistant took the audio recorder round so that the voice of those who contributed could be properly recorded. The participants seated in a circle. The other two assistants were writing down the responses so as to facilitate accurate transcription of the recoded information.

5.5.1.3 Interview Results at Lume Avete

The results of the interview are presented below. Table 5.8 illustrates the number of people interviewed and the household water usage. In all, 29 community members, both male and female participated in the study. With various household strengths and water usage stated by each person, it was found that on the average, the household strength is 5 people per household and water usage per household is 13 buckets (234 litres) this translates into 2.6 buckets of water (or 46.8 litres) per person per day. It was indicated by food vendors and mothers of kids that they use extra water for cooking food for sale and for washing babies'

clothing. The people said before the PV system was installed, they walked long distances about 2 km to look for water. In some of those villages they went to collect water, sometimes their benefactor community denied them water especially in the dry seasons. In those days, according to them each person used less than one bucket (18 litres) of water a day.

Table 5.8: Use of Water and Household Strength at Lume Avete (One bucket of water is 18 litres and figures in bracket are litres)

Number of respondents	Number of buckets used per households/day	Average number of buckets used per household/day	Number of people in a household given by all the 29 respondents	Average number of people in a household	Average number of buckets per capita/day
29	377 (6786)	13 (234)	145	5	2.6 (46.8)

5.5.1.4 Sources of Water and Purpose of Use

From the study, the people said they have three water sources; borehole, hand dug well and the PV system. They use the borehole and the well water for menial chores such as flushing toilet and washing. These facilities are used in the rainy season only when they produce enough water but during the dry season, the borehole and hand dug well get dry. Furthermore, the people said it is the PV system they mainly use for all their water needs (drinking, washing and cooking).

5.5.1.5 Sale of Water

According to the people, one bucket of water sells at GH¢0.02 meaning 50 buckets of water sell at GH¢ 1.00. It has also been revealed that the PV water is extended to 6 collecting points in the village and a designated vendor at each point is in charge of collecting tariff. Tariffs collected are given to the WATSAN committee caretakers who go round the water sellers every week and at the end of each month the moneys are banked in the WATSAN committee account in Akatsi rural bank. But before the PV facility came into being, one person used to sell the water at only one point since it was a borehole; and after one week, another person replaced the first person, this happened on shift basis.

5.5.1.6 Background of the PV System in the Community

About the background to the installation of the PV system, the key WATSAN member (LumWS 2, supported by other community members) revealed that officials from the Akatsi district assembly came with some foreigners who wanted to help communities with water problem, so the community was visited and selected. The people were called to a meeting with the donors from Denmark under Danish International Development Agency (DANIDA) project. Two options of power supply were given for the community to select their preferred choice (grid and solar). According to the participants, they selected solar energy because the donors told them that with solar, they would not pay tariff for the use of energy. They added that if they were to select the grid, it would mean waiting until the grid extension got to their community which might lead to losing the opportunity and also the grid power would have come with payment of monthly tariff but not so with solar. After that, the technical men from the CWSA did feasibility studies and came out with the cost of the project to be GH¢ 10,000.00 (about 3,000.00 USD). So the community was to pay 10% in cash and other costs in kind for which the community provided sand and gravel. They also dug the trenches for laying of water pipelines through communal labour. According to the people, by demonstrating that they could provide those things required from them, the PV system was brought to their community in 1998 and its installation completed in 1999.

5.5.1.7 System Operation and Management

Concerning the operation, maintenance and management of the PV system, participants said the water and sanitation (WATSAN) committee has been responsible and that the revenue generated from the sale of water are meant for repairs of the facility when it spoils. The people also said that there was no serious problem with the system ever since it was installed. One person however remembered an instance, according to him, one day a red light was seen on the system and water was no longer flowing so they drew the attention of the technicians from the district assembly to attend to it.

It was revealed that there is a caretaker who cleans the panels within every two weeks interval except during harmattan (early part of dry season) when the panels are cleaned every week. Security housing was provided, the community was told to prevent young people from throwing stones unto the solar panels.

When the people were to state what they considered to be the strength of the PV system, the response was that:

“The solar PV system is durable, because from 1998-1999 that the system was installed and we started using it, we did not have any problem as such. We also do not pay monthly electricity bill as we do for grid power in our domestic power usage. The current grid power load shedding we experience in the country these few years do not affect water supply; and provided the sunshine is available, water supply is regular, but not so with the well and borehole water which get completely dry during dry season. We shall for ever use solar” (LuCom 1)

However, on the issues about the weaknesses they found with the PV system, the respondents said:

“During harmattan season sunshine is not always available on some days; we suffer a little from irregular water supply from the solar PV system so we turn to borehole and well. But the influence of the harmattan does not last long, so solar is ok”. It may be that our storage tank is smaller than we need because our population is growing for all these 16-17 years. So we need to increase the capacity of the storage tank. We are thinking about installing poly tanks to the desired capacity” (LuCom 2).

When the interviewees were asked whether the solar PV has brought any change in their behaviour in relation to the use of water, this was the response:

“A lot of changes, namely: modernity, we no longer suffer from water related diseases. Guinea worm which is water borne infection was completely eradicated. Long hours spent in search of water from long distances has since stopped and we the women who normally collect water and who go round searching for water are also relieved. Our children now go to school regularly and on time. We now use more water at relatively lower cost than it used to be when the system was not installed. Some surrounding people also come to buy water from us” (LuCom 3)

Finally the people were asked if they had any other comments about the interview to which they responded:

“Yes, solar PV for water pumping is what is good for us. We are grateful for the researcher and his team, we are appreciative. We also have two other communities called Abusakope and Helegakope who are not having access to clean water, we want to please ask that you extend water to these communities if possible. We are appealing for help if any, or to advise us as to how we can help those two communities. We all used to do things in common such as communal projects but as we have this facility without them that cordial relationship is fading” (LuCom 4).

The results from the last case study are presented at the next section.

5.5.2 Case VII: Adaklu Anfoe

5.5.2.1 Demography of Adaklu Anfoe

Adaklu Anfoe is in Adaklu district and has a population of 1021 members. The community has four divisions. Until 2012/13, the community and the present Agotime-Ziope were under one district called Adaklu-Anyigbe district. Major occupation of the people is farming but few people weave kente in addition. Some of the women do petty trading in the agriculture produce. Like Lume Avete, some are also food vendors including palm oil preparation which requires the use of large volume of water.

The town has one basic/elementary school from kindergarten to junior high school level. It is currently connected to the grid which was not in existence when the PV system was installed in 1998/1999 by DANIDA. In spite of the grid, the PV system is still operated as a stand-alone facility.

5.5.2.2 Description of Method of Entry and Interview

The method of entry into Adaklu Anfoe followed the usual procedure adopted in all the other places. On the 18th February, 2014 the researcher went to the community and was led to one of the chiefs (AdAf 1) as the first contact person. The essence of the visit was explained to him which was about the research. The head chief was also visited in the company of the AdAf 1 and agreed date was fixed for the community meeting. On the scheduled date the researcher with two assistants went to conduct the interview at the community meeting.

The gongor beater (town crier) went round the community announcing the arrival of the research team. As the town crier went round, the chiefs and the WATSAN committee together with research team were already seated waiting for the people to come. At 7:15 am, everybody got seated and the chief's linguist was to lead the traditional greetings and introduction of the team. Customs demanded that the linguist ask the research team to tell in the hearing of the gathering, why they were in the community that morning. After this initial pleasantries, the researcher explained the questions on the interview guide and gave instruction as to how the whole interview process was going to be.



Figure 5.6: Adaklu Anfoe gongor beater (top left), people at community meeting (top right), the PV panels and research team (bottom left), Researcher audio recording and his assistant writing (bottom right) and second assistant taking photograph (not shown)

5.5.2.3 Interview Results at Adaklu Anfoe

Just as it was done at Lume Avete, the researcher was asking the question and directing or moderating the whole interview process. One research assistant was taking note another one taking the photograph. The audio recorder was carried along by the researcher (since the third assistant could not go with the team). Figure 5.7 shows some of the photographs taken during the meeting. On the top left is the gongor beater while part of the participants are seen seated under the PV water reservoir installed at the market place on the top right side. The research team is also seen standing by the installed PV panels at the bottom left corner of the figure while another section of the participants with the researcher are shown on the extreme bottom right corner. In all, 58 people participated in the study as shown in table 5.9. From the table, total quantity of water stated by the 58 people was 543 buckets (18-litre) and the total number of people in the household of the 58 people was 302. Hence average volume of water used per household per day is 9.4 buckets (169.2 litres). The average number of people per household is 5.2 and each person uses 1.8 bucket (32.4 litres) of water per day. But before the

system was installed, the people said each person used just about one bucket (18 litres) of water per day.

Table 5.9: Use of Water and Household Strength at Adaklu Anfoe (One bucket of water is 18 litres and figures in bracket are litres)

Number of respondents	Number of buckets used /day	Average number of buckets used per household/day	Number of people in households	Average number of people in a household	Average number of buckets used per capita/day
58	543 (9774)	9.4 (169.2)	302	5.2	1.8 (32.4)

From the interview, the respondents said they have 2 sources of water; direct from river Tordze and from the borehole pumped by the solar PV system. For all of these sources, the water is used for domestic purposes (cooking, washing and bathing). According to the people they used to fetch water from river Tordze free of charge but with the installation of the system, one bucket of water is now sold at GHC 0.10 the designated WATSAN member collects the money.

Background to PV system at Adaklu Anfoe

When the people were asked to give the background of how the system was brought into the town, nobody present was able to give accurate response. They said all they knew was that it was DANIDA people who installed the system for them in 1999.

5.5.2.4 System operation and management

About the management and operation of the system, the response was that it is the WATSAN committee who has oversight responsibility of the system and they liaise with the district CWSA on all technical matters concerning the system. The person who used to be the chairman was no longer in office. The new chairman who was expected to provide relevant information lacks this information. This is because according to him, he was appointed to the post without any training or handing over from the former chairman.

The people were asked if they ever had any problem with the system and the response is that:

“The problem is that when the system was first installed, DANIDA used to repair it even though the system rarely got spoilt. Later on, WATSAN committee and some of its staff had their capacity built through specialized training on the system by CWSA (DANIDA). They were taken through operations of the facility, basic maintenance culture, servicing of the pump, and care for the solar PV. However, the revenue generated from the water tariff was not adequate to cover full cost of the repairs. Sometimes, it took other citizens from this town

who are resident in Accra, the capital of Ghana to come to our aid by supporting us with money for the maintenance work” (AdAf 2)

On the issues of the strengths and weaknesses of the PV system, the people said the strength is that they do not pay tariff at all for the solar system as they do with the grid; on the weaknesses, the participants said they noticed in recent time that the water was not flowing well from the tap as such they were not getting enough water as it used to be the case. About how they thought the problem could be solved, the response was “*We do not know*”. The researcher asked another question as to whether the solar water pumping system has brought any change in their behaviour in relation to the use of water, and if any they were to give details. The response was that:

“Initially, when the water was flowing well, we did not have any problem but now that we hardly get water from the solar system we resorted to the use of the river” (AdAf 3)

With regards to whether there was a better option to the solar PV for water pumping, the response was that:

“Even though we have solar for water pumping, we also have grid power extended to our town. We notice that unless there is load shedding exercise or something wrong with the power supply, we always have grid power supply available” (AdAf 4)

On the issue of general comments, if any, they responded that:

“We see the solar PV is not giving us the volume of water we need, especially as our population keeps on growing. There is lack of proper management of the facility, lack of maintenance, repairs, and servicing. The installation site of the solar PV is not cleared and maintained properly so also is the reservoir. One other major problem we have with the solar PV is that the water from the system is hard and salty, while the river is sweet even though it is contaminated with a lot of impurities. People prefer using river Tordzi to the borehole water supplied by the solar PV because river Tordzi tastes well and better than the borehole water. The installed panels are sometimes shaded by the surrounding trees” (AdAf 5)

It was observed that the community was dissatisfied with the WATSAN committee because of their inaction and the fact that the water from the system was not as tasty as the raw river Tordze. So, since they were getting their needs met with the river, nothing was being done on the PV system.

Apparently the practice in the Adaklu Anfoe is the direct opposite of what takes place in Lume Avete. Although there seemed to be some kind of unity among the people, serious leadership deficiency was noticed. Even though the PV system is good, if other factors are not properly taken into consideration such as technical expertise, sense of community ownership and managements, valuable assets donated to some group of people would only be

a “white elephant” thus such system will not be put to proper use to serve its intended purpose.

In the next section, interview results obtained from solar energy industry players have been presented. This target group constitutes those who directly deal in solar energy technology including PV for water pumping. The industry players are deemed to have adequate knowledge about the technology regarding the PV adoption and market expansion in the country. Box 5.2 shows the codes used for the respondents from members of the Association of Ghana Solar Industry who took part in the study.

5.6 Results Obtained from Solar Industry Players

Box 5.2 Codes Used for the Interviewees in Ministry of Energy and Ghana Solar Industry		
Interviewee from Ministry of Energy (Power)		
MoE 1-	Deputy Director of Renewable and Alternate Energy	
MoE 2 -	Renewable Energy Engineer	
MoE 3 -	Chief Executive Officer of Energy Commission	
Interviewees from Association of Ghana Solar Industry Members (AGSI)		
AGSi 1	-	Respondent from Deng Solar Training Centre
AGSi 2	-	Respondent from Energiebau –Sunergy Gh Ltd
AGSi 3	-	Respondent from SNV
AGSi 4	-	Chief Executive Officer of Tiptop Food Ltd
AGSi 5	-	Chief Executive Officer of AECO Solar
AGSi 6	-	Component Manager of GIZ
AGSi 7	-	Chief Executive of Adzepa Energy
AGSi 8	-	Chief Executive Officer Sustain Ghana Ltd.

As reported in chapters 2, the Ministry of Energy and Petroleum in collaboration with its agencies is the sector ministry responsible for Ghana energy issues. The Ministry of Energy and Petroleum as of December 2014 was split into two; and Ministry of Power is now responsible for energy sources other than Petroleum.

The Association of Ghana Solar Industries (AGSI) and its clienteles are private-public institutions who are market players in the solar energy sector. Some of these institutions listed in Box 5.2 have also been interviewed in the course of the research specifically in the area of PV technology. The following section presents the results obtained from the interview.

5.6.1 Market Challenges Facing Solar PV Technology in Ghana

The deputy director of Renewable and Alternate Energy was the interviewee who participated in the study at the Ministry of Power. The Chief Executive Officers (CEOs) of AECO Solar, Sustain Ghana Ltd, Tiptop Food Ltd and Adzema Energy were also interviewed between October 2014 and January 2015. Others listed in Box 5.2 completed open ended questionnaire online.

The respondents have all indicated that the solar technology industry faces a few challenges in the country. Among them are: costs (initial and investment) of system, lack of knowledge about the solar technology; Finance (private/public); government's inability/unwillingness to implement legislation, e.g. net metering code; lack of technical knowledge and know-how; and less advocacy for solar technology in the most effective way.

The respondent who works at DSTC in Accra stated both initial and investment costs as a challenge facing the PV; he suggested his solution below:

"To promote or increase solar energy use in Ghana, taxes on system components should be reduced if they cannot be removed so that the cost could also be reduced in the process. Again financial incentives in the form of loans should be made available by the financial institutions with flexible payment terms to encourage customers to consider solar energy" (AGSi 1)

Similarly, the other respondent (AGSi 2) who cited a number of challenges suggested the following three solutions:

"Education is key. There must be aggressive education on the solar energy technology so as to educate the populace"

"Awareness creation is the next thing to consider. There are a lot of people in the country who do not know the potentials and possibility of the solar energy technology. When the awareness is created and people begin to appreciate the long term benefit that may accrue from the use of the technology it will promote market expansion. These are what I can say".

"Financing Mechanism. There must be financing mechanism where funds should be coming from the private sector. Means of payment for any solar facility should be gradual. When loans are given to those who may be interested in the solar energy facilities the terms must be softer and loan should be given long time to be repaid" (AGSi 2).

A third respondent also gave the following solutions:

"Solutions which deal with the high upfront cost of solar PV would remove the cost barrier. This includes hire purchase schemes, low/no interest loans for the purchase of the system".

“Awareness creation on solar energy” (AGSi 3).

The cost as a factor influencing the adoption of solar PV in general and for water supply in particular, is described as global factor by the deputy director of energy in the Ministry. He was responding to the question *“Do you still think there are some factors that militate against PV system adoption?”*

“Yes of course, there are a couple of factors; these are what I call global factors which are known to everybody in the industry. They are: Cost, lack of adequate financing mechanism and lack of human resource” (MoEP 1)

In terms of cost, he said although experts say cost has been going down at the manufacturing side to the user it is still high, citing that a typical solar lantern costs USD50 which is exorbitant for a household in rural Ghana. To the respondent, adequate and reliable financing mechanism to support solar energy utilisation will be a possible solution. He added that lack of human resource is yet another factor influencing adoption of the technology.

In the opinion of the deputy director, Africa, and Ghana for that matter is still struggling with the needed human capital to be able to support deployment of PV in very deprived areas and also to support maintenance and operation of these things in the long run. So having in place the requisite human capital at all levels, especially rural areas would make the cost of solar reasonably low and also bring service to the doorstep of the target groups.

According to another interviewee at the Ministry of Energy and Petroleum (MoEP 2), the cost of the solar systems should be reduced by the promotion of the manufacturing of key parts in the country. He also added that:

“Financial institutions should be encouraged to provide long term affordable loans to residents who are willing to purchase solar systems for their homes and businesses” (MoEP 2).

The chief executive officer of AECO Solar (AGSi 5) suggests tax holiday should be given to infant solar companies so as to encourage growth in such businesses. He is of the view that when infant solar industries are encouraged, more players in the industry will get on board leading to expansion of the PV market and hence break monopoly and cost will reduce.

When the executive officer of Tiptop Food was asked: “What do you see good or not good about the solar technology?” He said:

“It is maintenance free but its high initial cost is what scares a lot of farmers. In fact a lot of farmers come to see my farm but when I mention the amount of money involved, it kills their enthusiasm. In fact, considering the energy challenge we have now in the country, if there is

a way that the government can subsidise the solar system for farmers to get access to it, then it will even solve the energy crisis we are having currently (AGSi 4).

5.6.2 Solar PV Quality and Policy Dynamics

Policy formulation, implementation and monitoring is key and the quality of new technology such as PV system is a necessary requirement if the technology must be widely accepted for adoption and deeper penetration into the Ghanaian energy market. The function of the Ministry of Energy and Petroleum (now Power) is to formulate, implement and monitor policies that lead to reliable supply of energy and universal access to energy including renewables. Below are results from the field in relation to policy and quality of PV systems.

5.6.2.1 Policy for PV Systems

One of the questions put to the deputy director of energy (MoE 1) was

“If you are given the opportunity to make policy or to advise policy makers, what will be your policy direction in relation to PV system dissemination in Ghana?”

The response was that:

“The function of the Ministry is to formulate, implement and monitor policies that lead to reliable supply of energy and universal access to energy. So what we are doing here is to promote or develop policies that aim to address the militating barriers such as cost, lack of adequate financing mechanism and lack of human resource. As a ministry we have been able to put in place a Renewable Energy law- Act 832 which came into force in 2011 and this Act has a number of provisions that create the needed incentives for the industry, notably among them are:

Provisions for a feed-in-tariff (FiT) which is a financing policy incentive that gives preferential tariff to people who invest in solar at utility scale; provision for an obligatory purchase of energy from renewable sources; provision for what is called the net metering.

We have also put in a place a number of mechanisms to address the issue of inadequate funding for the sector. In addition, we have developed number of instruments and frameworks to enable us establish and operationalise the renewable energy fund.

We are also putting in place a dedicated entity, the Renewable Energy Authority will give special focus to delivery of renewable energy services to Ghanaians and beyond. We are still exploring new frontiers to create a very conducive macro and physical environment for renewable energy promotion in this country” (MoE 1).

To the same policy question, the CEO of Tiptop Food said:

“Policy wise, government institutions should put solar panel on the roofs, school management committees should invest into panels so also must be the ministries for instance; they must have panels as roofing material. Furthermore, government must introduce subsidies for solar systems. For solar, the pumps and panels are usually imported, so import

tax should be waved off by government to reduce the cost. Government must work with investors hand in hand to lessen the cost of the solar systems (AGSi 4)

To find out if there is any political challenge faced by the Ministry, the response is that there is no political challenge; the Ministry rather enjoys political support irrespective of government regime.

Awareness creation to educate the Ghanaian populace on the benefits of solar systems has been mentioned as a means of increasing the adoption of the PV systems by the interviewees.

5.6.2.2 PV Systems Quality

About quality of the technology, it has been reported that in order to maintain customers' confidence in the industry, it is necessary to seriously consider system quality issues. According to the deputy director of Renewable and Alternate Energy of the Ministry of Energy, a number of measures have been put in place to address the issues with poor PV product quality. One of them is having a rigorous process in procurement of such systems. In addition, in-country capacity is built to be able to address issues with quality. He stated that:

“...a very rigorous procurement process in procuring PV products into the country are embarked upon in which case experts are sent to the sources where these products come from; if it is Europe or China, a team of seasoned engineers visit the factory, test the product and make sure they meet the technical requirements set by the Energy Commission and the Ghana Standard Authority (GSA). Internally, capacity is built, through Ghana Energy Development and Access Project (GEDAP) support to equip the GSA with the state-of-arts testing facility that they are able to use to test any solar product; be it the panels, lanterns and others to ensure that they meet the requirements” (MoE 1).

Another programme is also put in place where the Energy Commission (EC) receives application from prospective dealers in solar and other renewable energy systems for a license. The license allows the dealer to send sample of his or her product to be tested by the GSA. When the product meets the standard quality requirements, then Energy Commission (EC) would issue certificate that allows that product to be brought into the country. The deputy director (MoE 1) further said occasionally, the EC goes to the market to select at random some of the products and subject them to independent assessment here in Ghana and even sometimes the samples are sent overseas for testing.

The Ministry and the Energy Commission are said to be working with the academia, the Energy Centre of the Kwame Nkrumah University of Science and Technology (KNUST) for technical training programmes. Some of the country's polytechnics have received support

from the Ministry in capacity building and supply of equipment for them to be able to train manpower, not only for installation but also to address some of these quality related issues. The academic institutions also develop curricula that address emerging trends of the industry.

It was also said that the Ministry was also partnering with development partners especially the German government to help improve the industry. The German government is partnering with the Council for Technical and Vocational Education and Training (COTVET) to develop low and middle level manpower capacity to respond to the emerging solar or renewable energy industry.

From the above results obtained from the sector Ministry and some of the industry players, it is obvious that some progress has been made in the promotion of the solar PV technology, the main progress being the enactment of the Renewable Energy Act 832 of 2011. In spite of such a progress, the rate of adoption of the technology is rather slow and the system's market size still small. Consequently, it is important to discuss factors influencing the adoption of the technology with reference to solar PV water system. This has been considered in chapter 7 where all the results from the study have been discussed and two frameworks developed.

Next is the summary of chapter 5 as a way of comparing the cases on thematic basis.

5.7 Comparison of Case Study Communities Based on Key Themes

Table 5.10 shows thematic comparison of the seven communities used as case study.

Cost of 18 litre bucket of water within the case study district ranges from GHC0.05 (at Akporke) to GHC0.20 (at Mangoase). However, during dry seasons when supply becomes scarce, private home vendors sell stored pipe borne water at GHC0.30 and stored rain water at GHC0.50 especially at Ziope and Kpetoe. Water sold at Lume Avete (in Akatsi South district) was the cheapest (GHC 0.02) because patronage of the PV system was good, no tariff was paid for electricity usage and water quality acceptable (similar to pipe borne water). The sources of water are underground (borehole) and surface water (basically river Tordzi and dam). Quality of water from the case study area is generally substandard except treated water delivered as pipe borne water at Ziope and Kpetoe. The same water quality issue arises in Adaklu Anfoe (although water analysis was not conducted). In the next chapter (i.e. chapter 6), the design, installation and the evaluation of the solar PV water system for this research have been reported.

In table 5.10, “**Substandard**” means water quality falls below WHO’s standard value
“**Acceptable**” means water quality is a little below WHO’s standard value but not an issue to warrant rejection by the community.

Table 5.10: Thematic Comparison of Case Studies

Themes	Kpetoe	Ziope	Akpoko	Kpota	Mangoase	Lume Averte	Adaklu Anfoe
Water Source	River/Pipe	Dam/Pipe & Well	Borehole	Dam/Borehole	Dam/Borehole	Borehole	River/borehole
Water Facility	Piped System	Piped and Manual	Mechanized system	Manual and Mechanized	Dysfunctional hand pump	Mechanized/ hand pump	Manual and Mechanized
Power	Grid &	Grid &	Grid	Solar PV &	Off-grid &	Solar PV &	Solar PV &
Supply	Manual	Manual		Manual	Manual when dam available	Manual	Manual
Water Quality	Standard pipe; substandard river	Standard pipe; substandard well water	Acceptable Little below standard but accepted by community	Substandard Both dam and borehole water below standard	Worst water quality (when available)	Acceptable; taste like urban water (not analysed)	Water from both sources substandard (not analysed)
Cost of Water (18 litre bucket)	GHC 0.10	GHC 0.15 from NGO	GHC0.05	GHC 0.10 for mechanized water	Used to be GHC 0.20 when facility was functional	GHC 0.02 Cheapest	PV water GHC 0.20 but not frequent in supply
	Rain water	Rain water		Free for pond water			River source free
	*GHC 0.30	GHC0.30					
	GHC 0.50*						

CHAPTER SIX: DESIGN AND PERFORMANCE EVALUATION OF SOLAR PV WATER SYSTEM AT KPORTA

6.1 Introduction

This chapter discusses the design, installation and performance evaluation of the solar photovoltaic powered water pumping system at Kporta in the Agotime-Ziope district as shown in the district map of figure 3.3. It starts with the description of Kporta community, choice and entry into the village for borehole mechanization with the solar water system, site visit by the researcher and his research team. The chapter continues with the description of the sizing and design, installation procedures, involvement and participation of the people and evaluation of the system's performance with regard to how the people collected water from it.

6.2 Kporta Community

Kporta is one of the communities found in the Agotime-Ziope district by the researcher during exploratory studies. The community is also one of the cases described in chapter 5. Additional description of Kporta has been made in this chapter in relation to the installed PV system.

6.2.1 Population and Occupation

As described in chapter 5, the community has a population between 200 and 300 (for design purposes population of 250 is used as explained earlier) people who are basically farmers with some being kente weavers and others particularly women prepare and trade in palm oil.

6.2.2 Climate and Geology

Kporta, like the Agotime-Ziope district itself, has mean monthly temperature ranging between 22°C and 32°C in the rainy season (Mid-March – July) though the mean value during the dry season (December – early March) is 37°C. The sunshine duration ranges from 5 and 8 hour per day with solar radiation values also ranging between 4.0 and 5.7 kWh/m²/day (being the range values of Ho the closest synoptic weather station) (Energy Commission of Ghana-EC, 2014).

The soil type found at Kporta is intergrade of forest, savannah and stony soils but contains abundant ground water. The top soil is sandy and suitable for mixing with cement to mold blocks for building strong houses and structures; therefore, a concrete structure was constructed for the stand of the PV water reservoir.

6.2.3 Selection of Borehole at Kporta for Mechanisation

The solar PV water pumping system was installed at Kporta when the researcher removed the NIRA hand pump originally fitted on the borehole. The following factors being in line with the research objectives were the bases for the borehole selection at Kporta.

- i. The need for the selected community to be located in the case study area;
- ii. Availability of abundant ground water in the selected area;
- iii. Abundant and regular sunshine in the area for mechanising the borehole with solar PV system;
- iv. The size of population of the people within the selected community and surrounding communities;
- v. Acceptability of the technology by the community.

In this section, the selection of Kporta has been explained.

During the exploratory study the boreholes at Wudzedeke, Kporta and Bedzame were identified as the water sources that could possibly be considered for mechanization since there was insufficient time and fund to conduct a new hydrogeological survey and drill a fresh borehole. Wudzedeke is the home village of the District Chief Executive and Bedzame is one of the villages surrounding Kporta.

The researcher discussed these three possible places with the district engineer who was also the district water and sanitation team's chairman. According to the engineer, most of the soils in the district are hydro-geologically difficult to access good yields of borehole water except Kporta community. His assertion was confirmed by the chief hydro-geologist and managing director of Pro-hydro Ltd who was interviewed during the initial exploratory study (this hydro-geologist had worked with the Danish International Development Agency-DANIDA and CWSA before going into private consulting).

Wudzedeke was not selected because the water supply from its two boreholes was inadequate as was found on the field. The community also has public rainwater harvesting system and river Tordze runs close to the village. In terms of developments, the town could be ranked third (after Kpetoe and Ziope) among all the 20 main communities within the district, in the assessment of the researcher. Bedzame is a smaller community (not included in the first 20 communities) and it is not centrally located with regards to other villages, so was also not selected.

The borehole at Kporta was selected because

- i. It is located in the case study area;
- ii. It has one borehole with abundant ground water (adequate yields) and a pond. However, the pond dries during dry seasons when water is needed most;
- iii. The whole district including the Kporta has abundant and regular sunshine in the area, a factor that favours solar photovoltaic water pumping as the means of mechanizing the borehole.
- iv. The size of population of the people ;
- v. The only elementary school servicing Kporta and its surrounding villages is in Kporta and
- vi. The communal labour the people offered for weeding, digging of the trenches (for the water pipeline and float switch cable) and other assistance they gave indicated that the community has accepted the technology for adoption.

The choice of this community was also endorsed by the District Chief Executive as the administrative and political head of the district whose final approval was essential although he wished the installation was done in his village.

6.2.4 Entry into Kporta and Siting for PV System Installation

After the initial exploratory study was carried out at Kporta, the researcher followed up a second time in order to inform the chief and the former water and sanitation (WATSAN) committee that the borehole in the community was selected for mechanization with solar photovoltaic water pumping system. They were informed that selection of their community borehole was approved by the District Chief Executive (DCE).

In response, the chief and his elders expressed their joy and acceptance of the project as dream came true. They explained that all the surrounding communities collect water from Kporta, especially during the dry season. The chief and his elders therefore gave approval for the mechanization of the borehole to be effected. During this meeting it was also possible to schedule a meeting day with the chief and the WATSAN committee for site visit by the research team.

On the third visit, the researcher with his team was able to select the site for the installation of the water reservoir since the borehole itself was few meters away from the village centre. Customs demanded that the team call on the chief and his elders to inform them of the site visit and the team was welcomed. The community's old WATSAN committee was also called to be present at the meeting since the issue for discussion was in their jurisdiction. A spokesperson for the chief and elders led the parties to have exchange of greetings. After that, the researcher was asked to state his mission (even though the chief and his elders were aware) and he also introduced his team members. After the message was presented and the introduction made, the discussion was then opened to all present for any questions and explanations mainly on where precisely the chief, elders and the WATSAN committee would want the reservoir to be sited and any related matter that could emerge from the meeting. Finally, the researcher and the team were officially welcomed with drinks (minerals and local gin- "akpeteshie").

Afterwards the site was visited and an agreed spot was marked for the installation of the water reservoir about 168 m from the borehole so as to bring the water to the doorsteps of the people in the community. The researcher and his team left the community on that day.

Since then, there had been regular visits and exchange of correspondence between the community and the researcher who also visited the community continuously to observe the people and get familiar with them in order to have better insight into their natural way of life, as part of the action research.

6.3 Selection and Use of Grundfos SQ Flex PV Pumping System

From a study conducted by EmCon Group of Company in Namibia, four brands of PV pump namely; Total Energie TSP, Watermax, Lorentz PS and Grundfos SQ Flex were compared to diesel water pumps to examine the cost effectiveness of solar water pumps. EmCon (2006)

reveals that the hydraulic load of Lorentz PS and Grundfos SQ Flex is the same and that both pumps are suitable for water needs at villages, for farm houses, lodges, and for livestock watering. These pumps have low maintenance requirements which make them attractive for remote water supply solutions; for instance, it takes 5 years to maintain Grundfos pump and 3 years for Lorentz pump. The Total Energie TSP pump also has low maintenance requirements (every 5 years) but can deliver much larger water quantities and so it can be considered for larger scale water supply requirements. The Watermax pump has the least hydraulic load and regular maintenance requirements (every one year) which make it dependent on maintenance service providers which cannot be afforded by village users (EmCon, 2006).

It is clear from the above findings that the use of Watermax pump compared to the three others is out. Lorentz pump compared to Grundfos is less durable. The Total Energie pump though suitable, has relatively larger hydraulic load than that of the Grundfos pump which is not necessary considering hydraulic load of 275 m^4 (i.e. $5 \text{ m}^3 \times 55 \text{ m}$) for this research work. Hence the Grundfos SQ Flex PV pump was chosen as the most attractive pump for the water supply system at Kporta. All the components constituting the complete PV pumping system (including solar panel, pump, motor and the controller, with design software) were manufactured and supplied by the same Grundfos.

Three solar energy companies were identified from where the PV system could be purchased. They were Sustain Ghana Ltd (who was a subsidiary and Africa zone representative of Grundfos Company); Energiebau Sunenergy Ghana Ltd (a joint partner of Energiebau Solarstromsysteme GmbH, Germany) and DENG Solar Training Centre (DSTC) / DENG Limited. Any of the three could have supplied the system because they are competent in the PV technology. Sustain Ghana Ltd was selected to supply and engaged to install the solar PV system at Kporta. This is because the consultant's price quotation for the PV system at the time was the least cost, his period to install the system was the earliest and as evidence to the researcher, the consultant installed a similar SQ Flex PV system in his house.

The next section explains how the PV system was designed using the Grundfos WinCAPS software.

6.4 Design of the Solar Photovoltaic Water Pumping System

In designing PV water supply system, some basic information was required. These are: meteorological data of the site (peak sunlight hour, solar insolation and hence design month),

the daily water demand of the community, the flow rate or the discharge and total dynamic head (TDH; i.e. the height to which water should be pumped taking into consideration head losses).

With a view to designing a correct solar-powered SQ Flex system, Grundfos has divided the world into six regions: North America, South America, Australia/New Zealand, Asia/Pacific, Southern Africa and Europe/Middle East/Northern Africa. Each region is divided into a number of zones according to the solar radiation in kWh/m² per day. Ghana falls within the Europe/Middle East/Northern Africa region and Accra zone.

Design Month

The insolation for Ho (the closest synoptic weather station to Kpota, the research centre) is shown in Table 2.5: Annual Monthly Averages of Solar Radiation (kWh/m²-day) at 19 Synoptic Stations (1993- 2002). Using the sizing tool integrated in Grundfos Win Computer Aided Product Selection (WinCAPS) with the fact that the research area falls within the Accra zone, the design month predicted by the software is February with insolation of 5.1 kWh/m² per day. This nearly matches with the average insolation value (5.2 kWh/m² per day) of Ho for February, the month when dry season reaches its peak and most of surface water sources dry up.

For manual calculation, August, the month with the minimum insolation of 4.2 kWh/m² per day was selected (see Appendix VII) as a rule of thumb.

Daily Water Requirement

The Community Water and Sanitation Agency (CWSA) provided a per capita water usage for design purposes to be 20 litres. That is 20 l/day per person. Hence water demand was $Q = 20 \times 250 = 5000 \text{ litres/day or } 5\text{m}^3$. Storage of water in an elevated tank is technically preferred to having battery in the PV pumping system as had been explained in section 2.7.4. It is also recommended that provision for three days' water storage be made (Barlow et al., 1993; EmCon, 2006; Khatib, 2010). For this system, a 15 000 litre tank was provided (i. e. 5000 l/day x 3 days).

Daily Discharge

An estimate of the required flow rate of the pump is determined by the following equation:

Flow rate q = (demand in litre per day/PSH per day) \times (hr/60 min) (Pelt, 2012)

PSH = Site insolation/1kWh as noted in section 2.6.2, hence for Kporta (using the value for Ho), PSH = 5.1 kWh/1 kW = 5.1 hr. Therefore the daily flow rate is:

$$q \text{ (l/min)} = \text{demand in litres per } \frac{\text{day}}{\text{PSH}} \times \frac{\text{hr}}{60} = \left(\frac{5000}{5.1} \right) \times \left(\frac{\text{hr}}{60} \right) = 16.34 \text{ lit/min}$$

Total Dynamic Head

Total dynamic head (TDH) of 55 m was used. This was made up of the sum of borehole depth from static water table to the top of borehole, elevation difference from the top of the well to the top of storage tank) \times 1.1 (Pelt, et al, 2012).

Hence Total dynamic head ***TDH*** = **$(43 + 2 + 5) \times 1.1 = 55 \text{ m}$**

Table 6.1 indicates the borehole parameters and other relevant quantities used for the determination of the TDH.

The next section explains how the PV system was sized using the Grundfos WinCAPS software. Manual design of the system is also presented in Appendix VII. The manual method provides the opportunity to less skilled designers who may not be able to use the software to design the PV water system and also provides a check on the computer results.

6.5 Sizing and Results of Sized PV System

The input parameters used in the Grundfos WinCAPS software are the: the daily water requirement of the Kporta community which was calculated as 5000 l/day; design month specified was February and the total dynamic head (TDH) being 55 m, from 6.3.1. Grundfos WinCAPS version 2011.01 which was available to the researcher was used to size the system in this research work.

6.5.1 Results of Sized PV System

Having inputted the required input parameters in the software, the PV system was sized and the complete results obtained, but the most relevant part of them is shown in Figure 6.1: Grundfos WinCAPS designed solar PV water system at Kporta. With these, five 80 W

Grundfos SQ Flex solar panels (Sun Module SW Poly RNA/D solar panel) with Grundfos motor-pump set, its accessories and control board were used in the mechanization of the borehole at Kporta.

For the panel used, each has rated power of 80 W; rated voltage and currents of 17.9 V and 4.49 A respectively. Table 6.2 provides the rest of information on the panel used for the PV system while table 6.3 and 6.4, provide information on the pump and motor respectively.

The panels have been connected in series according to the design and in this way, the electrical current of the system equal the current of one panel while the voltage increased by the multiple of the number of panels in series. Thus the voltage output from the five panels wired in series is the sum of all the voltages from the panels. For example, the maximum voltage output (rated voltage) from the five of the 17.9-volt PV panel wired in series is $(17.9 \times 5) = 89.5V$. The rated current (amps) output from these same panels wired in series is equal to the current (amps) output from an individual panel, 4.49 Amperes.

Two important points are worth mentioning here.

Firstly, the actual solar panel used in the work itself has different electrical parameters from those used in the software for sizing, but both categories of panels have the same power rating of 80 Watts, same motor/pump set and they are both Grundfos products. For instance in the design software (as can be seen on figure 6.1) the maximum power point voltage (rated voltage) is 33.3 V and the maximum point current (rated current) is 2.4 A. Hence, for the 5 panels in series, $Power = 80 \times 5 = 400 W$ or 0.4 kW

$$\begin{aligned} V_{total} &= 33.3 \times 5 = 166.5; \text{Current} = 2.4; \text{hence power is } 166.5 \times 2.4 \\ &= 399.6 \text{ or } 400 W \text{ or } 0.4 kW \end{aligned}$$

For the actual panel used in the research as shown in table 6.2,

$$Power = 80 \times 5 = 400 W \text{ or } 0.4 kW$$

$$\begin{aligned} V_{total} &= 17.9 \times 5 = 89.5 \text{ and the current } I = 4.49A \text{ hence power} = 89.5 \times 4.49 \\ &= 401 \text{ or } 400W \text{ or } 0.4kW \end{aligned}$$

Secondly, for the actual PV system installed in the community, one additional panel has been included upon the request of the chief and his people. They appealed to the researcher that with the mechanization of the borehole, they may want to extend the water point to some homes and also there is the likelihood of preparing and selling the water in sachet which in

Ghana, we refer to as ‘sachet water’. Incidentally, with the use of manual design method, six of the panels are required as shown in Appendix VII.

Table 6.1: Input Parameters for Designing the Solar PV Water System

Parameters	Quantity/Value
Maximum head pumped (elevation +static)	55 m
Quantity of water needed per day	5 m ³
Distance between BH/solar panel and Tank	168 m
Well depth	44.84
BH static water level	9.32 m
Pump installation depth	43 m
Solar insolation	4.2 - 5.7 kWh/m ² -day

Source: Field Data 2014

Table 6.2: Parameters of the Actual Grundfos Solar Panel Used

Parameters	Symbols	Values
Rated Maximum Power Output	P _{max}	80 W (-5/+10%)
Open Circuit Voltage	V _{oc}	21.9 V
Maximum power point voltage (Rated)	V	17.9 V
Module short circuit current	I _{sc}	4.78 A
Maximum power point current (Rated)	I	4.49 A
Power specifically @ STC, 25° C,	AM = 1.5	1000W/m ²
Fire rating Class		C
Series Fuse	SF	15 A
Field wiring Cu only 12 AWG insulated for 90° C		
The panel is GF crystalline Solar Panel	Dimension	96 cm x 68 cm
Mass of one panel 7.8 kg each of 6 panels	Grundfos	46.8 kg

Source: Derived from Trade Plate of the panel

Table 6.3: Grundfos SQ Flex Pump and Other Components

Parameters	Symbols
Pump	SQF 1.2-2, 1 x 95027328
Solar module	GF 80, 5 x 96616391
Switch box / control unit	CU 200, 1 x 96625360
Pump material	Stainless steel
Impeller	DIN W.-Nr. 1.4301

Table 6.4: Parameters for Motor (SQ Flex 1.2-2) incorporated into Grundfos Pump

Parameters	Symbols	Values
Power Input	P _I	1.4 kW
Rated Voltage	V _{ac}	1 x 90 – 240 V
Rated Voltage	V _{dc}	30 – 300 V
Rated Current	I	8.4 A
Rated Speed	N	500 – 3600 rpm
Power Factor	PF	1

From figure 6.1, being the software results obtained in the design of the PV system, highlights are: typical performance at solar radiation is 800 W/m^2 ; total power required is 400W or 0.4kW; average water production per day is 5.5 m^3 per day; peak flow 1.13 m^3 per hour (or 18.83 l/min) and number of modules (or panels) in series is 5.

By manual calculation using the same parameters as in the case of Grundfos software, six of the 80 W panels suffice as opposed to the five predicted by the software. However, when the minimum insolation of $4.2 \text{ kWh/m}^2 \text{ per day}$ is used in the manual calculation, almost seven of the 80 W panel would have been needed. Clearly the use of the software makes the design simpler than the manual method.

95027328 SQF 1.2-2 60 Hz

Input - summary

Water volume (max): 5 m³/day
 Peak month: February
 Head: 55 m
 Sun tracking: No (fixed)
 Solar data location: Accra, Ghana (5.6N, 0.2W)
 Data source: U Lowell : GHA4A, type P

Products

Pump: SQF 1.2-2, 1 x 95027328
 Solar module: GF 80, 5 x 96616391
 Switch box / control unit: CU 200, 1 x 96625360

Sizing results - summary

Typical performance at solar radiation 800 W/m²

Flow: 0.9 m³/h
 Friction loss: 0.9 m
 Total head: 55.9 m
 Total cable loss: 1.7 %

Water production, Peak flow and Price

Total water production per year: 2000 m³
 Avg. water production per day: 5.5 m³/day
 Average water production per watt per day: 13.68 l/Wp/day
 Peak flow: 1.13 m³/h

Cables and pipes:

Pump cable (pump - solar array)
 Length: 55 m
 Size: 1.5 mm²
 Pipe Length: 55 m
 Pipe diameter:

Solar module configuration:

Number of solar modules in series: 5, in parallel: 1
 Solar array rated power: 0.4 kWp
 Solar array rated volts: 166.5 V
 Sun tracking: No (fixed)

System performance - monthly average

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Water production [m ³ /day]	4	6	6	7	6	5	4	4	5	6	6	5
Energy production [kWh/day]	1.6	1.9	2.1	2.1	2.0	1.6	1.5	1.5	1.8	2.0	2.0	1.8
Radiation horizontal [kWh/m ² day]	4.2	5.1	5.6	5.8	5.6	4.5	4.2	4.3	4.9	5.5	5.3	4.7
Radiation tilt [kWh/m ² day]	1.3	1.4	1.5	1.7	1.8	1.9	1.8	1.7	1.6	1.5	1.3	1.3
Tilt angle [deg.]	5	5	5	5	5	5	5	5	5	5	5	5
Avg. Temp. [°C]	25	25	25	25	25	25	25	25	25	25	25	25
Temp. Variation [K]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

AC power (backup) - water production

Recommended minimum output: 1.5 kW
 AC 115 V: Produces: 1.31 m³/h
 AC 230 V: Produces: 1.32 m³/h

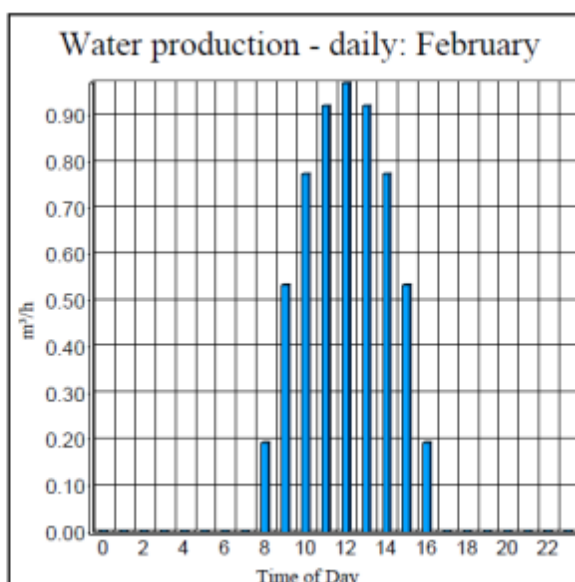
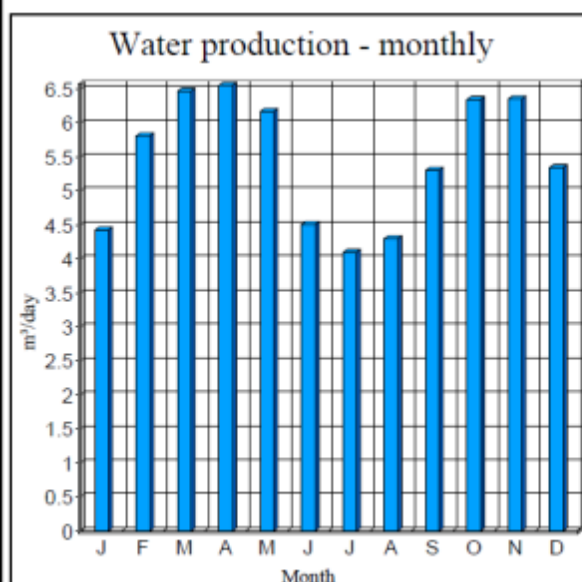


Figure 6.1: Grundfos WinCAPS designed solar PV water system at Kporta

6.6 Design and Manufacture of the Solar Panel Stand

The design and the manufacture of the PV panel support structure were determined by the dimension of each panel while the height was determined based on the clarity of the site to prevent the panels from being shaded by trees. It was also necessary that the support should be strong enough to withstand adverse weather conditions such as storm. Method of welding was used to manufacture the PV support structure as illustrated in figure 6.4a.

Each solar panel used has a dimension 96 cm x 68 cm and six of them have been connected in series along the width; the resulting combined dimension is 408 cm x 66 cm as shown in figure 6.2. The panel frame was made of mild steel angle bar with dimension 310 cm x 66 cm. There is therefore difference in dimensions of the panel support frame and those of the combined array of panels seen in the figure. The reasons are that the base support structure made of mild steel angle iron can easily rust when exposed to the weather (rain and dew, even if painted). This is not the case with the angle aluminum bar and the panel materials. So the base was constructed so that the panels could cover and prevent it from being exposed to the direct weather. Another reason is that, the cost of the aluminum angle bar is higher than that of the mild steel and if the complete structure were made of the aluminum the cost of the PV system would have gone higher. Finally, the length of the base support structure was made to fit onto the width of the existing borehole platform in order that the old (existing) platform could be maintained without the need for constructing a new one that would have come with cost.

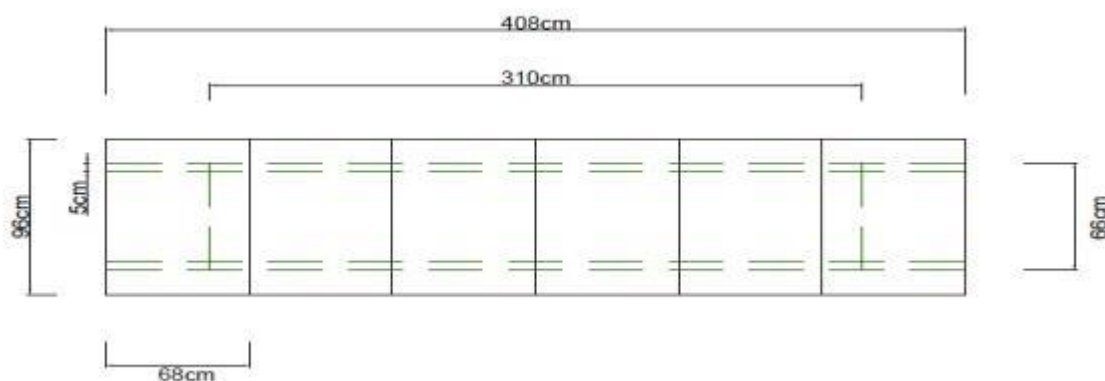


Figure 6.2: A sketch of the array of six solar panels used in the current research

The panel frame is supported on four stands of two pairs (one of which is illustrated in figure 6.3). The stands were made of 5 cm galvanized steel pipe. The galvanized structure has a dimension of 278.5 cm x 66 cm as seen in the figure 6.3. Before the panels were bolted onto

the base frame, two aluminum angle bars (i. e. the array mounting bracket and rack) were screwed onto the steel frame on both sides so that the panels were fixed to sit on, and be in contact with the aluminum bars rather than the steel frame.



Figure 6.3: Solar Panel Frame Stand

By this arrangement the panel would not rust or corrode. Parts (45 cm each) of the four stands were secured into the ground with concrete. The tilt angle of the panels was 15° (Argaw, 2004; Atsu et al., 2016) and by the use of compass, it was fixed facing south so that even though this is a fixed arrangement and not rotating to track the sun radiation, the panels can receive adequate solar radiation and make use of sufficient solar power. The welded solar panel stand was constructed by the researcher and the welding artisans in the Ho Polytechnic welding shop. Figures 6.4 (a-d) shows various stages of the installation and mechanization work of the borehole as considered in the next section.

6.7 The Installation Procedures

This section explains the participation and engagement of the community in the installation of the solar PV system. It also describes the actual installation of the PV system (the pumping facility and the overhead water tank).

6.7.1 Involvement and Participation of the People in the Community

To ensure the sustainability of the PV system, the community members have been involved in the project right from its initiation through to execution and commissioning. This is to give the members a sense of ownership which facilitates operation, management and maintenance of the facility that are key for sustainability of the system.

The men of Kportia community were involved in the installation process, they weeded around the borehole and along the path where the water pipes (discharge tubing) were to pass between the pump and the tank. The trench which would carry both the water pipe and the automatic switch wire was also dug by the young and old men of the community (including the chief himself). The people also carried sand and gravel for the manufacture of the platforms for the pump and the water storage tank stand. The community gave any assistance needed in terms of labour to facilitate the installation work. While figure 6.4 shows various stages of the PV system installation process, figure 6.5 shows the installed solar PV water pumping system (from welded PV stand to the installed system).

6.7.2 Fixing the Panel and Installation of Stand on the Ground

The installation procedure used for the mechanisation of the existing borehole was as follows:

1. Construction of the tank support using cement block and concrete (cement, sand, gravel, and water and iron rod) and fixing plastic poly tank on it.
2. Removal of the existing NIRA hand pump which was initially installed on the borehole prior to the mechanisation. The NIRA hand pump which was installed on the borehole prior to the mechanisation was removed by the Agotime-Ziope district Area Mechanic; i.e. a trained mechanic who has the skills to install and handle all maintenance and repair work on borehole and borehole hand pumps including the dual solar PV water pump. After removal of the NIRA hand pump, it has been seen that the pump was installed 21 metres in the 45 metre borehole.
3. Flushing (blowing) the borehole to remove bio fouling (mud and other impurities) from sidewalls and sediments from the bottom part of the borehole in order to make the water cleaner and purer.
4. Performing pump test to determine the capacity of the borehole, the static water level, and the depth of the borehole.
5. The installation of the Grundfos SQ Flex pump into the borehole using the manufacturer's manual as a guide. It is a dc submersible pump with its motor. The pump has a built-in check

valve. The pump, its controller and the panels have all been bought from the same Grundfos manufacturer, in other words, the setup is custom-built from Grundfos. It is installed with safety ropes, mounts and well seal. The submersible pump with the motor have been set to an installation depth at 43 m; an allowance of 2 m space has been left between the pump and the bottom of the borehole so as to prevent heavy silt and sand from entering the pump's intake and causing it to seize.

- i. Having fixed the panels on the frame and the stand, the men helped carry the structure to where the borehole is located and with concrete, the panel stand was buried into the ground to a depth of 45 cm.
- ii. Then the pump/motor set was electrically connected to the panel through the control switch board, CU 200, 1x 96625360. This was completed on 24th June, 2014.



Figure (a) Welding of panel stand



Figure (b) Fixing of panels on PV stand



Figure (c) Kporta men digging trench



Figure (d) Installation of pump set into borehole

Figure 6.4: Installation of Solar PV Water System



Figure (a) PV water storage tank

Figure (b) Installed PV array of panels

Figure 6.5: Installed Solar PV Water System

6.8 Management and Operation of the PV System

This section, describes the election of new water and sanitation management team (WSMT) for Kportia, their training, commissioning and the handing over the solar PV system to the community. The training was done by the district engineer as the principal facilitator assisted by the researcher. In this way the team will be aware that they are still under the authority and supervision of the district assembly and accountable to it.

6.8.1 Election and Training of Kportia Community WSMT

- i. The district engineer and the researcher visited the community on 25th August, 2014 to enable the engineer to inspect the project and arrange a meeting with the community.
- ii. He directed that the community should elect a seven member water and sanitation management team comprising five male and two female. The election was held few days after the meeting.
- iii. The seven member committee alongside three community development officers had a two day training on the Facility Management Plan (FMP) facilitated by the district engineer and the researcher (section 6.8.2). The community development officers have the responsibility of providing intensive education as well as monitoring and evaluation services to the WSMT.

- iv. The progress of the research project was periodically reported to the District Chief Executive as well as responses from the community.

6.8.2 Training Program for Kporta WSMT: 15th and 16th September, 2014

- i. Capacity Building - The WSMT members and the district community development officers were invited to the District Assembly for training on how to manage the water facility and related sanitation issues by the researcher and the district engineer. The essence of the training was to prepare the team members and build their capacity to know how to manage the solar PV system for its sustainability
- ii. A two day intensive training in a power point presentation format was given to the team members and three district community development officers (figure 6.6).
- iii. The training was centered on Facility Management Plan (FMP) developed by Community Water and Sanitation Agency (CWSA) but adapted for the new system.

The FMP is a document that can be best described as a constitution and operating manual on water and sanitation systems as far as Kporta community is concerned. Highlights of its content are:

- i. Kporta Water and Sanitation Management Team Constitution
- ii. Particulars of Technical Operator and the Standpipe Attendants (Service Providers)
- iii. Remuneration of Technical Operator and the Standpipe Attendants
- iv. Promotion of Good Health and Hygiene in the Community
- v. Role of Community Service Providers
- vi. Copy of the Feasibility Study Report (if any)



Figure 6.6: Training of Water and Sanitation Management Team (WSMT) (a) Training session (b) Group photograph of participants, engineer and researcher

6.9 Commissioning and Handover of the Solar PV Water System

This section discusses the commissioning and handing over of the solar PV water system by the district chief executive to the community.

- i. The District Chief Executive was informed about progress of work and the need to commission the facility and a date (3rd October, 2014) was set for the commissioning.
- ii. The community was informed about the date, time and the format the process would take and the need to assemble at their community meeting center.
- iii. A power point presentation was made to the community dwellers including school pupils on the solar water pumping facility; 113 participants attended.
- iv. The role of the chiefs, opinion leaders and the other members of the community in connection with the duties of the WSMT were spelt out in the presentation made by the district engineer.
- v. The Facility Management Plan which contains a constitution was explained to the people and later signed by the WSMT as a working document for the community.
- vi. Water seller was appointed to be responsible for the sale and accountability of the water.
- vii. The District Chief Executive (DCE) also talked to the people on the need to take good care of the facility which is the first of its kind in Kporta and its surrounding communities. He explained and also sounded a word of caution to the community that many boreholes drilled in the district became

dysfunctional because of lack of maintenance and vandalism. The DCE said the essence of paying for the water they collect was to generate revenue for maintenance and repairs when the system fails. He noticed that in his own community at Wudzedeke, some of the people preferred water collected from dam to water from the boreholes because they do not want to pay any tariff. The DCE emphasized the importance of account preparation which must be opened at the nearest rural bank, about 7 minutes' drive from Kporta.



Figure 6.7: Meeting with Kporta Community prior to commissioning of PV system

With the commissioning successfully done, the WSMT was to put measures in place to start selling the water to the people from December 2014 (i.e. beginning of the dry season) at the agreed price of 10 Ghana pesewas for 18 litre bucket. Normally, two water measuring containers are used to sell water: a 36 litre and 18 litre containers. They are used in the area to fetch water; in this way, it is easy to calculate the cost. Any other container must be measured against these standards since the seller cannot read the meter when any non-standard containers are used. These were the measures the team was asked to put in place before the start of the sale.



Figure 6.8: DCE with the researcher during commissioning of PV system

6.10 Evaluation on the Solar PV Water System and Results

This section provides a description of the experiment that led to the performance evaluation of the PV system.

The solar PV water system was installed on 24th June, 2014. Before the community people were asked to pay for the water they collected from the new solar system, they were allowed a period of about five months to fetch the water without paying any tariff. Two reasons can be given for this. Firstly, the month of June is a major rainy season in Ghana hence it was not prudent to sell water from the new system to the people when two other alternative water sources (rainwater and water from the dam) which were free of charge were available. Secondly, there was a need to draw the people to the new system, since a change from an old practice to a new one generally takes some time. It was clear to the people that the drudgery of using human labour to pump water (168 meters from the bush, where the borehole is constructed) when the original hand pump was fixed unto the borehole has been removed by the taps on the new solar system. Also the water collecting point has been brought to the

doorstep of the people. The impacts made by the solar PV system on the life of the community dwellers have been discussed in the current thesis.

It was important that actual experiment be conducted on the system either to confirm designed parameters (discharge) or refute them depending on the outcome so as to inform on reliability and potential replication of the system. Some of these tests were conducted and explained in this section. These include:

6.10.1 Determination of actual water discharge compared with designed

This experiment took place on a clear day such that the variation in the sun's radiation was not appreciable. In using a stopwatch and graduated plastic bucket to manually collect water from the pump directly, it was possible to measure the discharge as directed by the local supervisor in Ghana.

Pumped water was collected in a graduated bucket by the researcher every 5 minutes. Three experiments were carried out; in each case, water was collected three times and an average was calculated and recorded. Two research assistants helped in the experiment. One of them was reading the hand held solar meter while the other was doing the recordings. The total quantity of water collected from three average values summed up to 360 liters and the total time was 15 minutes. With this the average irradiance was 500 W/m^2 and the average discharges in litres/min, $Q = \frac{360}{15} = 24 \text{ lit/min}$.

A second similar experiment was conducted the next day and the discharge determined. This also translated to 20.83 litres per minute. Hence it is clear that by manually measuring the discharge, the pump discharge ranges between 20.83 and 24.00 litres/min ($Q = 20.83 - 24.00 \text{ l/min}$) translating into an average of 22.42 litres/min.

6.10.2 Assessment of volume of water collected monthly from the PV water system

Readings were taken on the water flow meter which has been installed at the collecting spouts of the taps to measure the flow from the storage tank on a monthly basis. This provided enough information on how much water was collected each month, starting from December, 2014. It has also given an indication about how the community people patronized the new facility within the experimental period. Furthermore, the quantification of water collected from the tank through the meter facilitated comparing the tariff paid by those who collected water from the new system with the recorded volume of water collected. Since the

system was designed for a number of people in the community based on per capita water consumption, this part of the experiment afforded the researcher with an opportunity to verify whether or not the people were making maximum use of the new system.

If the estimated 250 people in the community each collects and uses a minimum of 20 litres of water per day, from the PV system this totaling 5000 litres of water should be collected in one day. Since 18 litre bucket of water costs GHC0.10, this translates into $\text{GHC } 0.10 \times (5000/18) = 27.80$ Ghana cedis or GHC 27.80. This is equivalent to USD8.65 (USD1= GHC3.21 in 2013/2014). NB: GHC 4.20 = USD 1 (In August 2015).

6.10.3 Determination of PV power utilization by the pump/motor set.

This part of the evaluation made it possible to determine the quantity of solar power the pump/motor set used and hence the pump/motor efficiency. The control board displayed the solar power received by the panel when the system was running.

In this experiment, one research assistant read the power displayed on the control board and measured the electrical current and the voltage while the researcher read the hand held solar meter mounted on a small tripod. The second research assistant recorded the parameters being measured. A current/voltage clamp logger called Eel component multimeter was used to take the measurement of the system's electrical current/voltage and the tripod-mounted solar meter was used to measure the solar radiation in Watts per square meter (W/m^2). Pumping was done within 3 ½ hours (11:00 am to 2:30 pm) and the storage tank got filled up since there was some quantity of water in the tank before the test was done on that day.

The averages of typical experimental set of 71 measured data collected on the PV system on 2nd February, 2015 have been used to generate the regression graph illustrated in figure 6.9. However, the maximum, minimum and average values have been listed in table 6.5 below.

Table 6.5: Experimental Data on Solar PV Water pumping System at Kporta

	Solar Radiation (W/m^2)	Total Panel Area (m^2)	Solar Power (W)	Solar Power Utilized (Watts)	Current (A)	Voltage (V)
Average	471.7	3.92	1849	228.4	2.6	86.3
Max	714	3.92	2799	340	3.4	100
Min	53	3.92	208	60	1.2	50.0

6.10.2 Power and Efficiency Calculation

It can be seen in the table that the average solar insolation for the day was 471.7 W/m² with average PV system power utilisation of 228.4 W. The corresponding pump/motor electrical current and voltage were 2.6 A and 86.3 V respectively. This brought the electrical power utilized by the motor/pump set to (2.6 x 86.3 = 224.38 W).

Total PV panel area, $A_p = \text{number of panels} \times \text{area of each panel}$

$$\text{Total panel area, } A_p = (6 \times 0.96 \times 0.68) = 3.92 \text{ m}^2$$

Now,

$$\text{PV power recorded on system controller} = 228.4 \text{ W}$$

$$\text{Pump\&motor power} = I \times V = 2.6 \times 86.3 = 224.38 \text{ W}$$

$$\text{PV and Pump\&Motor power mismatch} = 228.40 - 224.38 = 4.02 \text{ or } 1.7 \%$$

The difference of 4.02 W or 1.7 % may probably be due to losses in the wires, and/or measurement errors. From figure 6.1, the value matches with the total cable loss of 1.7 % predicted by Grundfos. Next is calculation of the PV efficiency.

$$\text{PV eff.} = \frac{\text{Solar power received by PV}}{\text{Solar Radiation Power}} = 228.40 \div 1849 = 0.1235 \text{ or } 12.4 \%$$

The monthly consumption of water from the PV system by the people in the Kpota community has also been displayed on figure 6.10 in addition to rainfall pattern within the same period.

Table 6.6: Comparison of measured data with predicted values in kWh/m²per day

Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sept	Oct	Nov	Dec	Aveg
4.2 ^a	5.1	5.6	5.8	5.6	4.5	4.2	4.3	4.9	5.5	5.3	4.7	5.0
4.9 ^b	5.2	5.5	5.7	5.6	4.9	4.6	4.2	4.7	5.5	5.6	5.1	5.1

a. These are values obtained from the predicted radiation data generated by the Grundfos WinCAPS in the sizing and the design of the PV system used in this study

b. These are measured data reported by the Energy Commission of Ghana (2014)

From table 6.6, the maximum and minimum insolation values predicted by the Grundfos WinCAPS are 5.8 kWh/m²-day (in April) and 4.2 kWh/m²-day (in January/July) respectively.

The corresponding measured values reported by Energy Commission (EC) of Ghana (2014) are 5.7(in April) and 4.2 kWh/m²-day (in August). The Grundfos predicted and EC measured average monthly values are 5.0 and 5.1 kWh/m²-day respectively. These insolation values compare favourably as they nearly match.

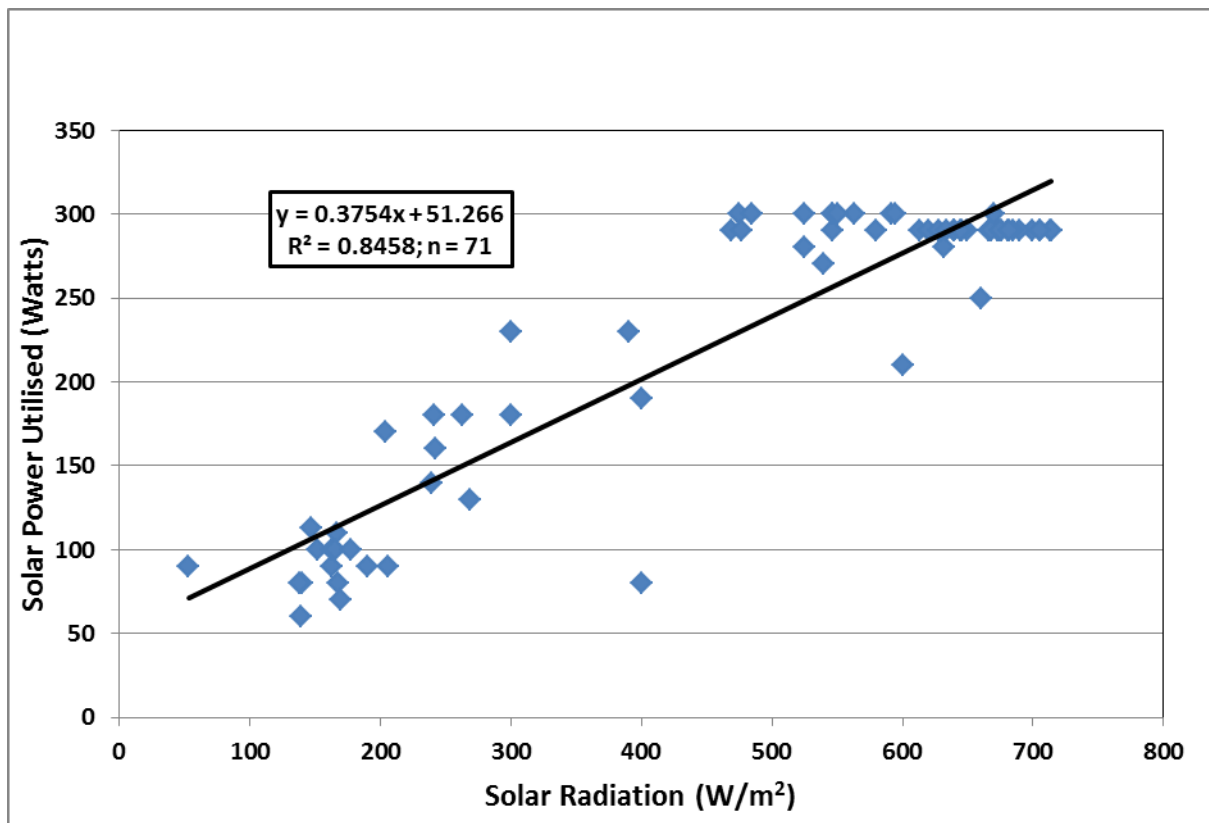


Figure 6.9: Regression Graph for System Power utilisation versus Solar Radiation

The regression graph (figure 6.9) between the two variables (solar power utilised by the panel versus solar radiation) clearly indicates that there is a strong correlation between the variables with R^2 value being 0.8458. This should be expected as the source of power for the system is the radiation from the sun and the flat plate collector in this sense is the array of (well cleaned) solar panels. This shows that the system power utilization directly depends on the solar radiation intensity and the correlation is positively strong. It may be stronger when the panels are clean from dirt. It is therefore necessary that the solar panels are cleaned of dirt (dust and droppings from birds) in order that they can receive and utilize as much solar radiation as possible. It is further explained that with the same system peak power, the storage capacity of the water tank (reservoir) could be increased in the future when

population in the community increases; or when the current alternative water source from the dam gets dry.

One observation about figure 6.9 is the large deviation in solar power utilised at (400 W/m², 80 W). This is probably an error in recording 80 W instead of 180W as suggested by the other point (400, 195); or it may be that when the researcher was about to take the reading, there was sudden rise in radiation after some period of overcast.

Figure 6.10 shows monthly rainfall and monthly water consumption (from the PV system) patterns. Data for the rainfall were obtained from the Volta regional office of the Ghana Meteorological Agency in Ho, the closest weather synoptic centre which is about 35 kilometers from the research village. Data used for water consumption (bars) were recorded from the meter mounted on the water fetching point of the PV system in Kporta. Both sets of data were collected from December 2014 to December 2015.

It can be seen that from the month of December, 2014 to February 2015 the water consumption (red bars) was increasing and reached a peak in February. Within the same period (dry season), the rainfall figures were between about 39 mm and 106 mm.

When the major rainy season (March-June) started in March and continued to reach almost the peak in June (blue line) the water consumption from the PV system began to decline steadily and reached the minimum by mid-June. This was due to the fact that as the rains began, inhabitants harvested rain water, the dried ponds (dams) was also being filled with the rain and less water was thus collected from the PV system. From mid-June, consumption began to rise up gradually to September while the rainfall sharply decreased as low as 12 mm in August before rising again. It can be explained that when the rainfall began to decrease, not much was harvested and so the people relied on the pond which had enough water but with only few people collecting water from the PV system (even though not much).

The maximum rainfall within the period was in October, 2015 with a value of 206 mm and the minimum was in December, 2015 with no value (0 mm). The period covering September to November is a minor rainy season followed by dry season.

The pattern seen in figure 6.10 should be expected. In Ghana, and particularly in the southern part of the country where the study was conducted, the communities in the case study area experience severe drought within the dry season when almost all water sources (especially

surface water sources) dry up. The water scarcity becomes very severe when the dry season stretches beyond February.

When this happened, inhabitants collected water from the solar PV system hence the increasing trend of water consumption shown in the figure 6.10 between December 2014 and February 2015.

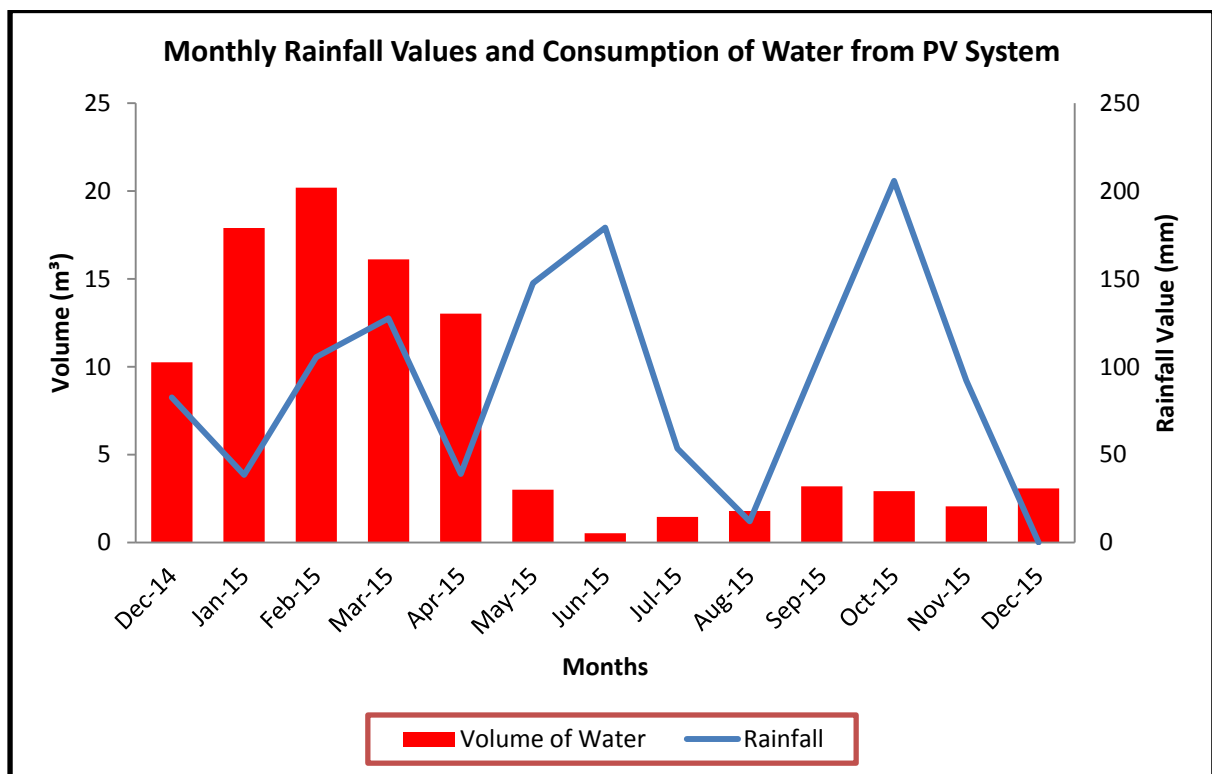


Figure 6.10: Monthly Rainfall and Water Consumption from the Solar PV System

The people of Kporta underutilised the PV system; while it was designed to supply 5000 litres (5m^3) of water per day and hence 15,000 litres for one month (of 30 days), the maximum water consumed from it in one month (February) was 20,195 litres (20.195 m^3). Similarly, only 95,487 litres of water was consumed instead of 1,825,000 litres the system was designed to provide in one year. This is just 5.2 % of the PV system's designed capacity for one year.

Figure 6.11 shows the pond at Kporta with the water almost overflowing its banks after the rains. Some patrons can be seen collecting water while the researcher was also tasting it. A running river water has self-cleaning mechanisms but a stagnant water of the pond seen at Kporta is not self-cleaning. More so, patrons walk into it with bare feet which could possibly

carry a lot of unhygienic substances into the water yet teachers in the local school stated that pupils come to school with water bottles and fill them with the water from the pond for drinking without treating it. This has the tendency of exposing the children to water related diseases.



Figure 6.11 (a) Pond at Kporta

(b) Researcher tasting pond water

6.11 Summary of Chapter 6

This chapter has presented the design and installation of the solar PV water pumping system used in the current study. It also evaluated the performance of the system so as to know its effectiveness and the impact it made on the people of Kporta in terms of water supply to the community.

It was found that the system performance was good as it was able to utilize adequate solar power to pump enough water for the community.

The PV efficiency calculated is 12.4 % and the percentage mismatch between the PV and motor/pump set calculated was 1.7 %; this difference was probably due to losses in the wires, and/or measurement errors. The value matches with the total cable loss of 1.7 % predicted with Grundfos software (see Figure 6.1: Grundfos WinCAPS designed solar PV water system at Kporta).

The Grundfos predicted and EC measured average monthly values are 5.0 and 5.1 kWh/m² per day respectively which indicates that the two values compare favourably.

It has also been seen that the use of the Grundfos software in the sizing of the PV system is more economical than using the manual method. While the software predicted the use of five 80 W panels, manual calculation gave almost six of the panels based on average monthly

insolation of 5.1 kWh/m^2 per day. However, with the use of the minimum insolation of 4.2 kWh/m^2 per day, almost seven of the panels would have been used for the same PV system.

The manually measured discharge from the PV system was 22.42 l/min , the discharge predicted was $1.13 \text{ m}^3/\text{h}$ or 18.83 l/min

The regression graph between the two variables (solar power utilised by the panel versus solar radiation) indicates a strong correlation with R^2 value being 0.8458. However, the researcher found that the people of Kporta could not make maximum use of the system since only 14 % of water was collected during the peak of the dry season when daily demand for it was the highest. Also, the total volume of water consumed from the PV system in one year was 95,487 litres (5.2 %) instead of 1,825,000 litres the system was designed to provide in one year.

Poor quality water (high mineral content resulting in water hardness and high salinity) from the PV system made the people to shift to the unhygienic water from the pond (dam); this was the main factor contributing to the low patronage of the PV system.

In the next chapter, all the results from the research are discussed.

CHAPTER SEVEN: DISCUSSION OF RESULTS AND DEVELOPMENT OF FRAMEWORK

7.1 Introduction

In this chapter, the results obtained from the study are discussed and two frameworks (Solar PV Water Pumping System Diffusion Framework for Ghana and Solar PV Water Pumping Financing Framework) developed to help enhance solar PV water pumping system adoption for rural water supply in Ghana. While the main findings were obtained from the quantitative and qualitative studies, the reviewed literature has also provided results which are all discussed below.

7.2 Discussion of Results on Rural Water Supply

This section will consider the study results, the sources and purpose of rural water supply; types and management of water facilities (by the water and sanitation management teams - WSDBs and WATSAN committees and by the people in the study communities); water quality and treatment; water usage and tariffs paid. It ends with discussion about the impact of water provision on the communities.

7.2.1 Sources and Purpose of Water Use at the Agotime Ziope District (Study Area)

The main sources of water for the people living in the case study area are ground (through boreholes) and surface water (dams, rivers/streams) as seen in Table 4.5: Main Source of Water. Most surface water (except the dam in Ziope) becomes scarce in the dry season making the area vulnerable to perennial water scarcity. One possible way of addressing this problem is to build bigger dams like the one in Ziope. In particular, the people of Kpetoe should construct a bigger dam than it is in Ziope so that they could store enough water especially during the rainy season. The dam would also serve as solution to flooding that engulfs the main bridge and cuts off the Kpetoe Township from people commuting between it and Ho, the Volta regional capital. Thus, the “one district one dam” project which the government rolled out in January 2017 could enhance the current water situation in the rural areas. Additionally, the people in communities should build bigger storage tanks to store large quantity of rainwater during the rainy season which they can use in the dry season (December-mid March).

The main purpose for which the people collect water in the study area is for domestic uses (96.1 %), shown in Table 4.6: Purpose for Water Use. The use of PV water system would supply both treated and underground water not only for domestic uses but also irrigation farming as it is with Tiptop Food Ltd (Vegetable farmer who uses the PV system reported in section 5.6.1 Market Challenges Facing Solar PV Technology in Ghana).

Indeed potable water coverage within the case study communities is not adequate especially with the continuous increase in population; the situation is rather worse during the dry season. Adequate supply of water facilities for groundwater abstraction is necessary and this makes a good case for the PV system particularly in dry season. The usefulness of the system would be enhanced during this lean period since it is unaffected by drought.

The next section discusses management and types of water facilities employed in the study areas and their functionality.

7.2.2 Types and Management of Water Facilities in the Case Study Area

This section discusses the available types of facilities employed in the communities to abstract and deliver water to the people.

Three types of water facilities were found in the field; the Ghana Modified India Mark II (GMIMII) and NIRA hand pumps, grid powered submersible pumps and solar PV systems (at Lume Avete and Adaklu Anfoe). They have been reported in chapters two and four.

Most of the communities in the case study area where boreholes are found use GMIMII (deep well) hand pumps with the exception of Kporta where a NIRA (shallow well) hand pump was fitted unto the borehole. However, the hand pumps have centralisers which are the weak parts and so need regular replacement for sustainable use of the facility to access water.

The geology in this area also makes access of groundwater difficult using the deep well hand pumps and may require hydro fracture to break open the aquifer rocks. Because of weak facility parts; and difficult hydro geology of the area, there is the need for regular maintenance and support (from the district assembly) to keep the water facilities functional. However, this is not the case in the Agotime-Ziope district so the facilities in the communities perform poorly.

The poor performance of water facilities is mainly attributed to lack of supervision and support from the district assembly to the benefiting communities coupled with dormant or

non-existent water and sanitation management teams in almost all the communities studied. Consequently, many hand pumps within the district have become dysfunctional as shown in Appendix VI.

On the other hand, in Lume Avete where the water and sanitation management team is working as expected, the PV system is supplying adequate and sustainable water to the people. As a result, water is sold at a very low price (the lowest tariff among the seven cases); patronage is good since a large quantity of water is collected from the system and substantial revenue generated from water tariffs. The most successful study community was Lume Avete.

For water facilities to function as expected and be sustained, water and sanitation management teams in small towns and communities should be reconstituted (as at Kporta) and regularly supported by the district assembly. Adequate monitoring and supervision with logistical support from the assembly are critical. Water collectors must also be willing to pay the required tariffs so that enough revenue is generated for regular maintenance of the facilities; there should not be any issues with paying tariffs because water is an economic good and needs to be treated as such.

7.2.3 Water Quality and Treatment in the Study Area

The quality of water found in the case study communities is not clean; (i. e. it is unhygienic). The bacteriological and physicochemical tests conducted on samples of some of the water sources in the district for which results have been presented in chapter 5 also confirmed that poor water quality is a major issue in the district.

Apart from difficulty in accessing groundwater reported in section 7.2.1, water from underground sources have a high mineral content while water from surface sources have issues with turbidity and pathogen (except treated pipe borne water). The quality of water found in the case study area (as shown in chapter 5) is therefore of a major concern to the inhabitants as well as the district assembly, which by policy (Community Water and Sanitation Agency -CWSA Act 564), is the owner of the water facilities and projects. Owing to the poor water quality, almost all the cases considered (with the exception of Lume Avete and Akpokorpe) frowned on the use of water from their boreholes for drinking and washing but used unhygienic surface water instead. The people perceive water collected from these

unhygienic sources to be better than what is collected from boreholes because such water is not salty and also not hard (it lathers well with soap).

Another concern is the fact that water from unhygienic sources are no longer given the requisite treatment before use even though various water treatment methods have been listed by some of the respondents. Observation made in the field (at Kporta, Kpetoe, and Adaklu Anfoe) indicates that even if rural water was treated in the past when the rural water and sanitation projects were in the hands of the development partners such as Danish International Development Agency (DANIDA), it is rarely treated nowadays. People fetch surface water (ponds and rivers) and drink once the water is visibly clear. Some people believe that the rivers have been used since their grand parents' era and there had been no serious illness or death so there is nothing wrong with drinking such water without treating it. This practice exposes the people to health hazards as they also wash and defecate close to the bank of these water sources.

Poor water quality (high salinity and hardness) also has an adverse effect on the solar PV system installed and used for this research work at Kporta. The inhabitants underutilised the system since it supplied poor quality water. Even the chairman of the reconstituted water and sanitation management committee who should have encouraged his people to collect water from the PV system did not; he and his family, instead collected water from the pond. The chairman's attitude has the tendency to discourage people from patronising the PV system.

The water situation at Adaklu Anfoe is worse than it is at Kporta. The raw water from river Tordze becomes the only source in the community (Adaklu Anfoe) since the PV system does not pump sufficient water from the borehole; even the little water pumped is also hard and salty. The use of untreated river Tordze for domestic purposes poses health threat to the community while at the same time renders the PV system economically useless. At Mangoase where water scooped from a dry pond was full of mud, the treatment used was to add alum (chemical) and allowed the water to settle. However, at Lume Avete where the PV water looks visibly clear and tastes like pipe-borne water, the people collect most of their water from the PV system; it thus makes a great impact in the Lume community and remains the preferred choice for water supply.

Non-patronage of water from the PV systems has the tendency to send negative signals to other communities as if the technology is bad. This would be due to the networks and

communication between communities that may communicate negative perceptions of the PV technology. A worse situation may occur if a PV system should be mounted on a borehole which has poor quality water, compared with a competing alternative water source that may be perceived to be of better quality (tastier, softer, purer and free of charge). This problem is greater if the PV system is not producing adequate water as is the case with Adaklu Anfoe community.

Water treatment was one of the issues that attracted donor support in the past. Communities and their WATSAN committees were trained and equipped with water treatment skills in boiling, filtration, use of alum and aeration (exposure to the atmospheric air) as reported by respondents and recorded in chapter 4. This helped many communities to eradicate water related diseases especially guinea worm which affected most communities. It could be that the communities are immune to those diseases now or available cases may not have been considered alarming to draw public attention.

Water treatment plant (e.g. osmosis to remove salt or to filter the water) powered by solar PV will be a possible solution to the problem but will have cost implications for the whole system. Such a system needs to be patronised sufficiently so as to generate adequate revenue within the shortest possible payback period, not only for defraying treatment cost but also for additional maintenance cost. On the other hand, in a situation where the PV produces good quality water as in the case of Lume Avete, a solar PV system will be the most welcomed rural water facility because it would be cheap (virtually no maintenance and overhead cost). This was demonstrated by the people in Lume Avete.

7.2.4 Water Usage and Tariff Paid

The quantity of water collected and the tariffs paid for it are crucial for determining whether or not an expensive water system (such as the PV) will make any economic sense or not. Therefore this section discusses the purpose for which water is used and; the cost and quantity of water collected.

In order to generate adequate revenue from water tariff, people should be willing to collect enough water and pay economic tariff (since water is an economic good). It has been revealed by the study that on average, about two (1.9) of 18-litre buckets of water is used per capita per day. From table 4.14, 88 % of the respondents indicated that they use between 1-2 buckets (18-litre) while from sections 5.3, almost two (1.9) of the 18-litre bucket of water (or

34.2 litres) is used per capita per day reported under each case studied. It is only at Lume Avete that almost three (2.6) of the 18-litre bucket of water (46.8 litres) is used per capita per day. These figures are encouraging since the standard design figure (from Community Water and Sanitation Agency- CWSA) is 20 litres per capita per day.

The study (both the quantitative and qualitative) revealed that in all the communities where the research was carried, most people pay for water and the main mode of payment is “Pay-As-You-Fetch” (73.5 % i. e. 95 % of valid responses) except those who collect the commodity from pond or dam (scooped land holding water) and rivers for free of charge.

Obviously people will use enough water when the supply is adequate to meet the demand and the quality meets standard (or at least acceptable). Indeed when water supply matches with or exceeds demand (and the quality is also acceptable to the people), the cost becomes cheaper and so people turn to use more of it. This increases and enhances revenue mobilization and ensures timely repair and maintenance of the water facility thereby sustaining it. Salaries and other overhead expenses are also easily settled. This was demonstrated at Lume Avete and to some extent Akpokorpe. Conversely when water demand exceeds supply and the quality is poor (high mineral content), it discourages people from using more water or they may turn attention to unhygienic sources which are free of charge (e. g. Adaklu Anfoe and Kporta). In such cases, the facilities become dysfunctional for lack of maintenance; they are left in the bush to deteriorate and PV panels shaded by trees. Facility management committees should always adopt the best practice to provide good services to their people.

7.2.5 Impact of Water Provision on Communities

It has been seen; both from literature and through current field study that regular and adequate supply of clean water to rural communities impact a great deal on the lives of the people (Adow, 2013; Limantol, 2009). The following section discusses the impact of water provision in the communities where the study was conducted.

7.2.5.1 Setting up Small Businesses

The availability of safe drinking water contributed to the setting up of small businesses such as brewing local drinks in addition to preparation of ‘awusa koko’ (porridge) and food selling. ‘Kenke’ and ‘banku’ (both from mainly maize) are staple food eaten by people from almost every tribe in Ghana. A large amount of water is used to soak the maize for about two or three days before being grounded into flour. The flour is mixed with water and left for at

least one day to ferment before using it for kenke and/or banku. The stew and soup used to eat with them also require large volume of water to prepare. Water is also needed for washing the plates which patrons of the food use. Apart from that, women use water in cooking palm (red) oil from date palm tree. Through these businesses, the socioeconomic status of the people improves and standard of living increases. A similar observation was made by Limantol (2009) in the northern part of Ghana where, apart from selling food and local drinks, the women do shear nut processing. Shear nut is washed with water after the husk is removed; it is then grounded and soaked in large volume of water and stirred to obtain shear butter.

7.2.5.2 Reduction in Long Queues at Water Fetching points

In terms of social impact, the water systems contributed to reducing the drudgery associated with fetching water and long queues at borehole sites and public pipe stands; a situation that benefits mostly women.

The people of Kporta said that during the dry season water collectors formed long queues at the borehole site as each person waited for his or her turn to fetch water. This could result in conflict situations and breaking of good relations between people of the same family or communities.

The same was said of those who fetched water at Akpokorpe when the borehole was not mechanised. Normally these queues were formed during rush hours in early mornings (5:30-7:00 am) and evenings (3:30-5:30 pm). At Kpetoe where public pipes are used, queues are formed when water is pumped after many days of acute shortage; during this period, people send drums to collect water and deny those with 18 litre bucket access to water. The practice leads to conflict situations as people with smaller containers feel deprived by water collectors using bigger containers. Women (usually lactating mothers) who carry baby at their back suffer most when this happens. With the advent of mechanised system (PV at Kporta and Lume; grid at Kpetoe, Ziope and Akpokorpe), the long queues are reduced because water supply is regular.

7.2.5.3 Reduction of Absenteeism at School

In Kporta and Lume Avete, it was revealed that provision of water reduced pupils' and teachers' absenteeism from school. In Kporta, a school has been established which now serves as a nodal point for pupils from all the surrounding villages. Children now go to

school more regularly and promptly than when the water systems were not available in the community. These pupils bring water bottles from their villages and fill them with the borehole water for drinking during the dry season or with dam water in rainy season (when the water is sufficient and does not smell). At Lume Avete, it was revealed that illnesses which children suffered in the absence of good water have come down considerably with the provision of the PV water facility. These observations agree with what has been reported by Adow (2013).

Water provision is often discussed in tandem with the energy required to operate water facilities. On the basis of this, the next section discusses power supply for water delivery.

7.3 Discussions on Energy for Rural Water Supply

Apart from energy policies implemented in the early 1970s, the 30 year National Electrification Scheme (NES) was initiated in 1989 as reported in chapter 2. Because the focus of the scheme is on electrification with access mainly through grid extension, it is possible that the scheme could face a challenge if renewable energy, in particular, solar energy is not integrated (Bhattacharyya, 2013). Solar power has considerable potential to serve households in dispersed off-grid rural settlements and peri-urban locations of the country where the government currently pays high subsidies for grid electricity connections. This practice does not make any economic sense.

It has been pointed out in chapter 2 that, there is a great disparity of electricity access between the urban and the rural coverage in the country. Adopting an alternative decentralized approach in electricity supply is necessary for off-grid communities and small towns to consider stand-alone PV systems for their power supply. Small towns having grid connectivity may also consider grid-connected PV systems. This would ensure reliable supply of potable water from their facility. The fact that Ghana has abundant sunshine and there is potential for solar energy use, adopting PV pumping in decentralized systems would be a sensible choice.

7.3.1 Power Supply in Rural Water Provision in Case Study Communities

In section 7.2.2, three main types of water supply systems have been listed as found in the communities. Out of these, two are mechanised systems with solar PV (Kporta, Lume Avete and Adaklu Anfoe) and with grid (Kpetoe, Ziope and Akpokorpe).

Power supply for water provision comes mainly from the national grid but the supply is unreliable (table 4.18). Consequently, the water delivery to communities with grid powered piped system or mechanized water facilities are adversely affected. The implication is that in such times that power would not be supplied the people risk not having safe drinking water. They would thus stay for days without water or resort to unhygienic sources as observed during the study tours to the communities and discussed in the next section.

7.3.1.1 Preference of Solar PV Water System over Hand Pump

Although provision of borehole fitted with hand pump generally makes life a bit better, it is more time consuming getting water with such a system especially when it is NIRA hand pump. This pump, being a reciprocating pump, delivered a lower volume of water than the PV system (submersible rotary pump). The NIRA pump mounted on a good yielding borehole produces less than 13.5 litres of water per minute (as explained in section 5.2.5) while the installed rotary submersible solar PV system at Kpota delivers a higher volume of water per minute. An average of 22.42 litres per minute was recorded (see section 6.10.1).

Again, the PV system has water storage tank which stores three days' quantity of water required; and those who collect water do so through two taps on the storage tank of the PV system which are easy to operate by young and old people. The system is closer to the people than when the NIRA hand pump was in use. This makes the PV system the most preferred choice especially in the dry season.

7.3.1.2 Lack of Training on Solar PV Water System

With the exception of the area mechanic in the district who was trained to install and repair hand-pumps and the single-panel PV systems (provided by the Ghana Cocoa Marketing Board), the water and sanitation team members lacked the skills needed to install and repair solar PV water systems. The non-existence of the technical expertise is one of the factors militating against high rate of the PV system adoption. In fact, there was only one such technology found in the district when the study was conducted.

Unless the PV system is piloted (as in the case of the hand pumps when they were first introduced in the country) and technical training given to the people, it would be difficult for the communities to appreciate and adopt the technology. It is thus recommended that the district assembly in conjunction with PV training institutions should organise and run short courses for water and sanitation management teams, community and PV agents (as is already

being done by JICA in other communities) to build capacity and train technicians at local and community levels.

The next section discusses other factors that directly influence the adoption of the PV. They are mostly barriers to the technology diffusion.

7.4 Factors Influencing Adoption of PV System in Ghana

There are some factors identified from the field and literature that influence the adoption of the solar PV pumping system in Ghana. For easy and massive adoption of the system, these factors are discussed alongside possible solutions in the following section. This may help to promote and initiate long term investment into the technology.

7.4.1 High Upfront Cost of the Solar PV Systems

The high upfront (initial capital) cost is the most significant factor or barrier to renewable energy technology deployment and solar PV in particular. This factor is known in literature and stated during the interview sections by all the stakeholders who participated in the current study reported in section 5.6 of chapter 5. Tse (2000) and; Attachie and Amuzuvi (2013) report of high system cost, lack of financing for solar energy consumers and service providers, perception of high cost of solar PV by the public and lack of interest of potential market groups (real estate industry and public educational institutions). See also Amankwa-Amoah and Sarpong (2016).

For the current research, the complete cost of the 480W PV system installed at Kporta was about GBP 7,600 (see Appendix VIII) clearly, it would not be easy for any rural community to afford this amount just to procure PV water system if no assistance is given from the government or development partners because rural dwellers are low income earners.

In order to make the initial cost low, the government allows tax exemptions for all renewable energy systems that are imported into the country. What is paid usually includes harbour handling charges (cost of conveyance in the harbour). However, when the products are imported in their individual components form (but not in bulk as a complete system), the tax exemptions do not apply and the tariff becomes high (such as import duty ranging between 5 % and 20 %) in addition to 15 % Value Added Tax on the components and solar PV accessories (AGSI, 2011). The difficulty here is that one must have a huge sum of money to buy a complete renewable energy technology (RET) system to enjoy the tax waiver.

Otherwise one imports components and pays the duties on each of them. The Ghana Revenue Authority, (specifically the Custom Excise and Preventive Service) should be well educated and given clear directives on tax collection regarding RET. This will encourage more investors to invest in the technology to ensure that the target of having 10 % of the national energy mix coming from renewable sources by 2020 are achieved.

Government subsidy and; affordable and client-friendly financial assistance should be provided. Subsidies that are targeted at the poor to enable them to have access to electricity from solar PV would not only encourage usage and sustainability but also contribute to scaling up access to the resource in off-grid locations (Obeng and Evers, 2009). Other financial options (figure 7.2) have been developed and are discussed further at the end of this chapter.

7.4.2 Lack of Awareness about the Solar Energy Technology in Rural Ghana

There are many benefits that can be derived from the use of solar PV application in rural settlements in Ghana but which are not known to people in those locations. This is a barrier militating against the adoption of the technology.

In the case study area, although some of the student-respondents who completed the questionnaire demonstrated some knowledge about solar energy, most of them did not demonstrate knowledge about the full PV technology itself. The students only indicated that solar energy is regularly available, constant and free of charge. They may have read about it in school because some aspects of the new school syllabus deals with the technology. The PV technology is not known to the water and sanitation committee or board members in the district who normally lead their communities in the selection of which water facility to acquire. Indeed the WSDB chairman (KpWB 5) stated that he had no idea about the technology. Even some of the senior personnel at the district assembly did not demonstrate satisfactory knowledge about the PV technology. They could therefore not argue on the ground of the high initial cost. None of the women group demonstrated any knowledge about the technology just as other respondents referred to above. Clearly there would not be the motivation to adopt the technology in rural areas if the district assembly senior management personnel are not educated and supported by the CWSA in a like manner the hand pumps were piloted.

The director of Renewable and Alternate energies of the Ministry of Energy, Ahiataku-

Togobo revealed that even though aspects of the Renewable Energy Act 832 are communicated to specific people when the need arises, there has not been any clear communication approach put in place for renewable energy, (Ahiataku-Togobo, 2013). The director attributed this to the fact that there are aspects of the regulatory instruments for Feed-in-tariffs which were still being worked on by the Ministry of Energy. Awareness raising was identified as one solution to this problem. This should be done through education in order to help achieve the change from the old system to a new one; for instance changing a hand pump system to a more modern solar PV system. Awareness about where to get technical services and spare parts to repair PV systems for sustainability of the system is paramount. The provision of relevant and accurate information for acquisition and maintenance of PV systems is important for adoption of the technology. Information about financial assistance and method of access of such funding is also very important for prospective adopters. For instance, AGSi 4 stated that he got assistance from the Ministry of Energy which rolled out a PV project and publicised it in the daily newspapers. His farm has now become a demonstration centre for the Ministry and students who need to study and acquire practical experience about renewable energy from both within and outside the country.

7.4.3 Lack of Client Trust and Confidence in Solar Energy Products

Another barrier identified from the study is the poor performance of some of the installed PV systems; this engenders a lack of client's trust and loss of confidence in the longevity of both components and systems.

It was observed that some of the solar PV water pumping systems have failed but there was no attempt to put them back into operation. This unnerves prospective users and interest groups and diminishes their trust and confidence in the durability of the PV systems. PV product quality control is essential and key to creating interest and enthusiasm in PV market. This observation has also been reported by JICA in the study it conducted for the Ministry of Energy and Petroleum in 2011.

7.4.3.1 Procurement and Supply of Renewable Energy Products

Interviewees from stakeholder institutions underscored the quality issue and the need for the country to be able to maintain customers' confidence in the industry. Apart from that, the Ministry and its decentralized agencies have also been working to build in-country capacity to be able to address issues on quality of PV and other RET products. Procuring quality RET products (and hence PV system) alone are not enough to guarantee clientele's trust and

confidence if the technical skills and knowledge necessary to install and operate such systems are not acquired by designers and installers. The next section discusses this capacity for the installation and maintenance of PV systems.

7.4.4 Lack of Capacity for Installation and Maintenance of the PV Pumping System

The study revealed that a lack of the necessary human resources to disseminate, install and maintain solar photovoltaic water pumping systems also accounts for the poor or low receptivity of the technology in the country. Developing solar photovoltaic agents to market the PV in the rural areas is essential for the effective installation and maintenance of the system in these remote areas; and one of the interviewees, AGSi 1 indicated that his centre trained PV technicians. (The researcher had a similar training with the centre in 2007).

However, the challenge with this training programme is that it is centred in the city (Accra) far away from the rural people who should take advantage of it. Another challenge is that the training fee is too high for rural people to afford. What is necessary therefore is the strategy adopted by Japan International Cooperation Agency (JICA) where the programme is held in the rural communities so as to train technicians and community members. By so doing, the systems will not be maintained by the PV technicians alone but also by inhabitants under the community ownership and management principle. The model developed by JICA (the development of human resource at two levels) is working in some parts of the Ghanaian rural areas. It is a result of comprehensive time tested research that the Agency (JICA) has conducted and which is reported in the next section. The levels are community and PV agents.

i. Community Agent

The Community Agent (CA) is a knowledgeable local person who plays a leadership role in disseminating relevant information with respect to PV and its application in rural communities.

ii. PV Agent

The PV Agent is someone who should support the CA and expand PV business opportunities in rural communities. The relationship between the two is that the PVA supports several communities and CAs while the CAs support users of PV in the communities. Table 7.1 outlines the activities of the two Agents as adapted from JICA (2011).

Beyond the capacity building for rural communities in solar PV technology it was revealed during the study and reported in section 5.6 that the Ministry has established training centres

in 2 of the ten polytechnics of Ghana and in 2 selected public universities. This will help build capacity for middle level manpower trainers who can individually train more people as they go into private solar businesses themselves as graduate employers.

Table 7.1: Expected Activities of PV Agent and Community Agent

PV AGENT	COMMUNITY AGENT
Marketing of PV in rural areas	Promoter of PV in the Community
Supply chain development of PV components	Operation of PV systems
	Technical assistance for users of PV systems
Community Agent training	Support of PV users
PV user training	
Business networking into rural areas	Small sales and battery charging business in PV component
	Community Solar System operation

JICA, 2011

Training institutions should be encouraged and supported to run PV installation and maintenance courses for community and PV agents. There should be satellite training centres to build capacity and trained technicians at local and community levels.

7.4.5 Absence of a Viable Industry and Lack of a Coherent and Coordinated Policy

The barriers include the absence of a viable industry due to lack of a coherent and coordinated policy on energy that takes renewable energy technologies into consideration. This is evident alongside conservative manufacturing and production environment (Tse, 2000; Attachie and Amuzuvi, 2013). Some of the reasons given for lack of viable PV industry and market in the country are high taxes leading to cost build up and threatens a viable market by scaring the private sector from investment in manufacturing solar energy systems (AGSI, 2011). However the implementation of the Ghana Energy Development Access Projects (GEDAP) in the country since 2006 has allowed a few communities to enjoy solar energy systems. Even though the single panel PV water system donated by the Ghana Cocoa Marketing Board (COCOBOD) has made the situation better in recent times, its performance is not as good as the system installed in this research work. Government needs to subsidise more quality PV systems as it did for the Ghana Modified India Mark II hand pump; this would make adoption of the PV system easier and faster.

From the aforesaid, it is obvious that institutional and policy issues have constrained market development for renewable energy. Too much dependence has been placed on grid electrification (in the National Electrification Scheme) to achieve universal access of reliable electricity supply to all communities in the country; this retards the rapid diffusion of the PV system. Government policies and programmes concerning renewables, with special reference to solar PV, must not be ambiguous or cumbersome which prevents the policies being easily implemented.

For the solar PV water pumping system to be successfully diffused into the Ghanaian market these factors must be addressed. The next section integrates these factors to develop two frameworks that would address the issues raised; being essentially institutional, economic and technical.

7.5 Development of Framework for PV Water System Adoption

In developing the frameworks, the need to broaden the existing PV market segments and the financing models in the country was considered. The two new frameworks are the outcome of the current research and can be adapted for other systems such as solar home systems (shs). In fact there is no model known to the researcher which is used in the diffusion of PV system in Ghana. The discussion however begins with the supposed existing market segments of PV technology in the country. The solar photovoltaic market segment as it currently exists in Ghana includes the regulatory and training institutions; PV designers/installers and the clientele (Frimpong, 2013). However, this “structure” does not provide adequate opportunity for massive deployment and diffusion of the PV for water pumping as some market segments have been left out. For instance, financial and donor (NGOs, development partners) institutions have not been included explicitly in the current practice within the country.

The two new frameworks have therefore taken into consideration the existing PV market and those other market segments which are crucial for the achievement of the desired market penetration and diffusion of the technology.

In the next section the new frameworks (figures 7.1 and 7.2) have been discussed. They have been developed on the basis that government policies need to be aware of concerns that relate to the security of energy supply, environmentally-safe technologies, sustainable development, rural development, employment generation, women empowerment, and poverty alleviation.

In addition, appropriate strategies for the implementation of the regulatory instruments in the RE Act 832 need to be put in place for attainment of the objectives of the new frameworks. Solar PV, particularly for water pumping, should thus be considered as one of the key choices for the delivery of energy and water services within the country.

7.5.1 Solar PV Water Pumping System Diffusion Framework for Ghana

The solar PV water system diffusion framework for Ghanaian market in figure 7.1 is a proposed structure to accelerate diffusion of PV water pumping system. It illustrates six players in the solar PV system instead of the four existing players reported by Frimpong (2013).

7.5.1.1 Regulatory Bodies

The Ministry of Energy, Energy Commission and Public Utility Regulatory Commission play various regulatory roles in the Ghanaian energy sector while the Ministry of Water Resources Works and Housing with its decentralised institutions (NCWSP, WRC) do same for the water sector. These regulatory bodies and public utilities provide incentives for the expansion of services to rural areas and need to be enforced by unambiguous national rural development policies as noted by Meier (2012). Such policies adapt laws and formulate measures creating an enabling environment for rural PV water supply development (licensing, concessions, permits, pricing mechanisms, capacity building, incentives, financing schemes, quality assurance, and technology advice etc.)

The regulatory bodies need to provide equal opportunities for PV to compete in an energy market dominated by conventional energy sources by removing financial and market barriers, specifically removal of custom duty and value added tax (VAT). RET-friendly pricing framework, particularly for PV water system should be instituted to encourage utility companies (electricity and water) to adopt PV energy in their supply. With the enactment of the RE Act 832 this should not be an issue but the provisions in the Act must be fully implemented without any ambiguity. There must be policy (e. g. tax waiver) to encourage financial institutions and insurance companies to have a favourable PV loan scheme and insurance cover for prospective PV users. Government must create the enabling economic environment for financial institutions to give customer-friendly loans to prospective PV water system adopters at affordable interest rates and with relatively long repayment periods. Special subsidy must be provided for PV system consumers and solar service providers and

installers. There must also be policy (in a form of subsidy) to induce real estate developers to make provision for PV water system in building designs just as there is policy for public buildings to be disability friendly. Currently the water ministry lacks legal power to enforce guidelines and standards. All challenges confronting the issue of licenses and certificates to players in the PV and water industries both public and private must be removed. For some of these challenges, see section 2.11.

The regulatory bodies are expected to ensure that only quality products are brought into the Ghanaian PV market by certified suppliers.

7.5.1.2 Investors and Donors /Development Partners

The investors and donors/development partners (bilateral and multi-lateral) are groups of people or corporate bodies (Ghana Energy Development and Access Project donors; Churches - foreign or local, and NGOs) that provide funding (grants and/or loans) to the government of Ghana through the two main sector ministries (Ministry of Power and Ministry of Water Resources Works and Housing). They also sign Memorandum of Understanding (MOU) with the government before they are permitted to do business in the country. This includes the provision of PV based training equipment etc. to the rural areas and the training institutions such as universities and polytechnics. The PV systems they bring into the country must meet the quality standards set by the Ministry of Energy through the Energy Commission and Ghana Standard Authority.

Rural water provision in Ghana mainly depends on donor funding (loans, donations and grants), hence there is the need to have conducive political and economic environment to draw in these development partners.

7.5.1.3 Training Institutions

In Ghana, the main training institutions are Deng Solar Training Centre, the Energy Centre of Kwame Nkrumah University of Science and Technology, Koforidua Polytechnic, the University of Energy and Natural Resources and Tamale Polytechnic.

In the proposed framework for PV diffusion (figure 7.1), it is expected that all the ten polytechnics in Ghana (eight of which have been upgraded to Technical University Status in 2016) must engage in solar PV water pumping system training. In addition, well-resourced

technical institutes may also be considered for the training purposes. This will enable the training centres to get closer to rural communities since these institutions are in the ten administrative regions of Ghana; and are closer to the rural and remote locations than centralised training centres such as DSTC in the capital, Accra. Other training centres can easily be instituted closed to rural areas by each polytechnic or technical institute as is currently done in Takoradi Technical Institute. Getting PV training centres close to the rural population has a lot of advantages: Training costs will be low (reduced accommodation and travelling cost) and more rural community dwellers will take advantage of the proximity of such centres. Awareness about the technology will increase and the capacity in PV technology will expand. The Ministry of Energy in collaboration with Japan International Cooperation Agency (JICA) provided training centres in a few communities as has been reported in the previous section. Apart from providing technical training to build the capacity for their customers, the training institutions themselves should enhance their research and development (R & D) skills so as to go into the manufacturing of the PV components such as solar panels and pumps and the assembly of the systems.

The next section discusses designers and installers (solar PV service providers) within the framework.

7.5.1.4 Designers and Installers

PV designers/installers are technical and business people who are involved in the design, installation and supply of solar PV water systems such as members of Association of Ghana Solar Industries (AGSI), some of these companies have been listed in Box 5.2. It is important that they themselves are trained and licensed as stated above and are able to install quality PV systems in the country and give customer-friendly services. They should also ensure that each member of their trade association upholds the ethics of the profession to encourage good practice. Following the designers/installers are financial institutions and clientele who can be expected to play a vital role in the diffusion of the PV system and are therefore discussed below.

7.5.1.5 Financial Institutions

In Ghana, financial institutions consist of banks, insurance companies, savings & loan and ‘susu’ (daily savings) collector associations and other micro-finance operators that provide

financial assistance to their clientele (buyers) at affordable interest rates. As noted by SENG (2013):

“Microfinance institutions and strategies provide one means of overcoming this challenge of initial capital outlay for end users of PV systems” SENG (2013).

With support from the government, financial institutions should develop affordable and customer-friendly loan packages for prospective PV technology adopters to acquire solar water system for their farms, private homes, and institutions. It should be similar to car loan packages which banks have provided for staff of corporate institutions to acquire private means of transport and property. With institutional guarantee from the district assembly, communities can collectively organise themselves and then go in for loans to procure the system at affordable payment terms.

7.5.1.6 The Clientele of PV System

The clientele (PV system consumers) in the solar PV water system diffusion framework for Ghanaian market (figure 7.1) includes public and private institutions, individuals, cooperative farmers, communities and real estate developers. They must all be trained on the PV so as to build their own capacity for the design, installation and the maintenance of the solar PV pumping system. The training may enable them to understand the technology principle and issues relating to system qualities and cost (e. g. the principle of pay-as-you-go). The “pay-as-you-go” is a flexible way of increasing the capacity of the PV system incrementally as more funds are available or when the need to expand existing system arises; this is possible since the PV system is modular in nature.

Also 'pay as you go' strategies could be adopted as a means of removing the challenge of initial capital outlay as well as training of technicians and possibly clients to provide maintenance services in order to reduce the perceived risk”(SENG, 2013).

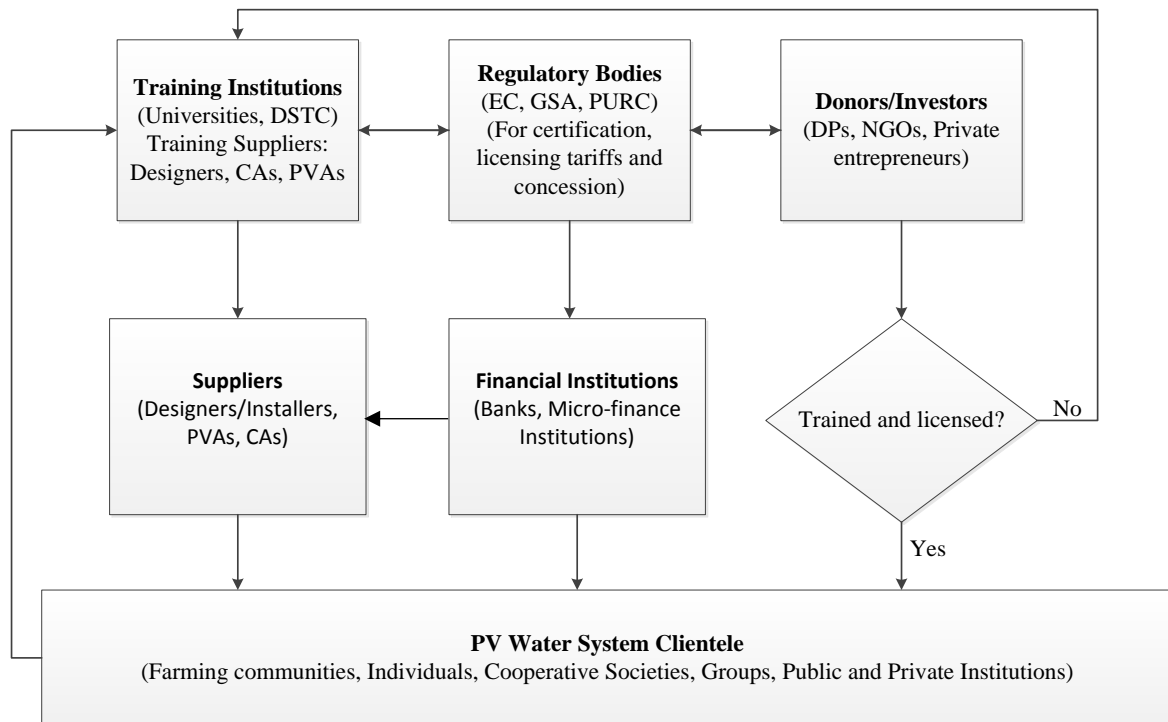


Figure 7.1: Solar PV Water System Diffusion Framework for Ghanaian Market

The PV system installed in Kportia for the current study for instance, could easily be extended to where the water may be needed using the “pay-as-you-go” method.

Summary of the Framework

The following explanation summarises the activities involved in figure 7.1. The arrows indicate the flow of service from one segment to another.

REGULATORY BODIES (RBs) & TRAINING INSTITUTIONS (TI)

The RBs roll out rural projects and programmes, and publicise these in the daily newspapers to enable interested individuals and communities to access them. One example is the Roof-Top Photovoltaic (PV) System project rolled out in 2015. The RBs collaborate with Training Institutions (TIs) to develop tailor-made training curricular and materials to train and certify prospective applicants (PV system suppliers, designers/installers and community agents). The two-way arrow depicts the flow of services between the RBs & TIs.

REGULATORY BODIES (RBs) & DONORS/DPS /PRIVATE SECTOR

The Ghanaian Regulatory Bodies (Power and Water Ministries and their agencies) receive assistance (grants and loans) from her development partners (DPs) for rural water supply infrastructure provision. Similarly, the private sector (capital investors and entrepreneurs)

contributes to the provision of rural water supply facilities. Politicians also enact Laws to support RBs. After receiving the assistance, the RBs also give some concessions to Donors/DPs and investors such as permits and free import taxes especially for facilities donated free of charge. The two-way arrow depicts the flow of services between the RBs & DPs.

DONORS/DP & CLIENTELE

Donors, investors, DPs and Non-Governmental Organisations (NGOs) provide rural water facilities to communities, public and private institutions. They should provide for clientele training as well. The decision box with “yes” or “no” underscores the need for this training.

RBs & FINANCIAL INSTITUTIONS (FIs)

The RBs are expected to negotiate conditions with the FIs so that customer-friendly loan schemes are provided to ensure that PV technicians, installers, suppliers and customers have access to affordable loans for the acquisition of PV water systems. FIs that design special PV loan schemes should receive some concessions such as tax holidays from the RBs.

FIs & SUPPLIERS DESIGNERS/INSTALLERS & CLIENTELE

FIs are expected to provide affordable PV loans to suppliers (some of who are listed in Box 5.2), designers/installers, Community and PV Agents for the acquisition of a PV system. Similarly, the FIs should extend the same loan facility to the clientele. Hence there is one arrow from FIs to suppliers and another to clientele.

TRAINING INSTITUTIONS (TIs) & SUPPLIERS DESIGNERS/INSTALLERS

TIs shall provide competency based training to suppliers, designers/installers to qualify them to be licensed and certified. Ho Technical University (the researcher’s employer) has recently received a grant from the Energy Commission to train technicians to design, install and maintain Roof-Top mounted PV systems.

SUPPLIERS & DESIGNERS/INSTALLERS & CLIENTELE

Suppliers, designers/installers provide installed PV systems to the clientele and train them to perform routine maintenance (e.g. weekly cleaning of PV panels especially in the harmattan season when the atmosphere becomes dusty) and troubleshooting (e.g. when the PV control board indicates faults) on the system. For instance, the fault indicator on the control board of the PV installed at Kportia is a sketch of a mechanic holding tools on his shoulder. When the indicator light shows on this feature any member trained on the system could tell that there is a fault to draw the attention of the installer for correction.

CLIENTELE & TIs/RBs

Clientele apply to RBs through TIs to access rolled out projects/programmes. Their request is expected to be on a demand-response basis as this principle ensures community ownership and management of rural water facility discussed in chapter 2 and illustrated in Figure 2.16: Procedures for selecting beneficiary communities for water supply facility (CWSA, 2012).

Having considered the PV market structure which is supposed to address problems related to policy, education and training, PV awareness, quality and sources of funding, the next framework (fig. 7.2) addresses mainly cost related issues (e.g. high initial cost).

7.5.2. Solar PV Water Pumping Financing Framework

The financing of solar PV water pumping system is another key factor considered in the diffusion and adoption of the technology. Figure 7.2 illustrates a second framework developed in the current study to facilitate and promote rapid adoption of the technology in Ghana. It is based on the earlier work of Mainali and Silvera (2012).

Mainali and Silvera (2012) present PV financing models used for solar home systems in Nepal, but not for PV water systems as in the current study. The terminology applied to the technology defined in the current framework are in line with CWSA of Ghana policy and provided by the regional engineer (RCWS 1) and the monitoring officer (RCWS 2) stated in section 6.2 of chapter 6.

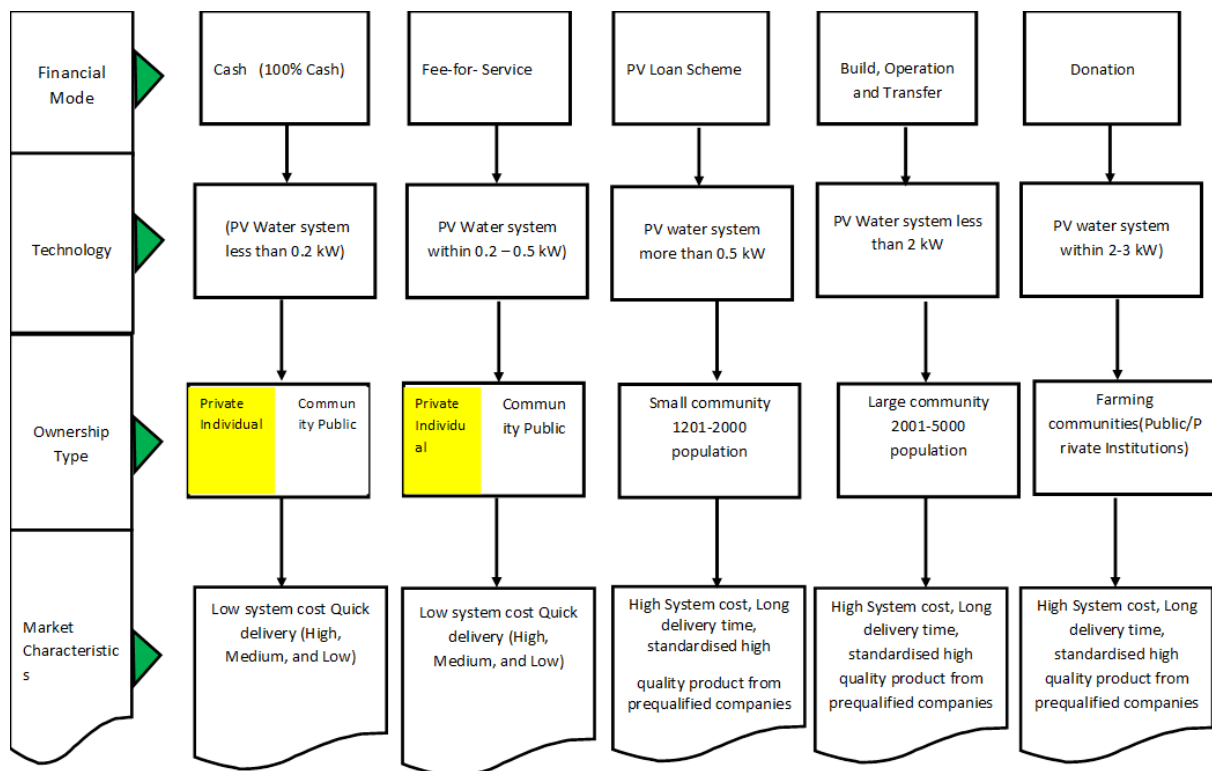


Figure 7.2: Solar PV Water System Financing Framework (Adapted from Mainali and Silvera, 2012)

In Ghana, the existing financial models being used include Fee-for Service (FfS), Donation and Direct Cash purchase. For the new framework, two other financing models of procuring the solar PV water system have been included making five. These are the PV utilisation loan scheme (PVULS) and Build-Operate-Transfer (BOT) financial models.

7.5.2.1 Cash Purchase (100 % Cash)

The cash purchase is when a customer will buy the PV water system and makes an upfront payment for the total cost of the product (100 % upfront cash payment).

The technology defined (see section 5.2.2) by CWSA is the Point Source water supply system to provide safe drinking water to a target population of up to 300 people defined in section 5.2. Those targeted under this option are mainly private individuals (those who have their own homes particularly in the cities), and, in some cases, private institutions like schools, health centres and communities similar to Kpota. It is expected that low capacity solar PV water systems (about 160 Watts, similar to COCOBOD's installed systems; see chapter 2) should replace hand pumps and be fitted onto hand dug wells and boreholes.

The cash model within the framework is geared towards relatively low installation costs, quick delivery and diverse quality (high, medium and low) PV water systems. Although this scheme is simple, it has the tendency to exclude poor people who may not have cash to pay for the full upfront cost of the system.

The next option considered is the Fee-for-Service model.

7.5.2.1 Fee-for-Service (FfS)

A Fee-for-Service (FfS) scheme is characterized by charging a fee for the use of PV technology to users instead of transferring ownership to them. A typical PV rural electrification project using solar home system run on fee-for-service in Ghana is Renewable Energy Service Project (RESPRO); this is reported by JICA (2011).

In the current framework, the fee-for-service financial model is expected to apply to Point Source water systems supplying water to a target population ranging between 301-1,200 people. Those targeted under this option are mainly private individuals (those who have their own homes) and communities, similar to those listed under cash model including public organisations with a larger population size. The service provider will manage, operate and maintain the system for as long as the end users use it.

The FfS model aims to providing high installation, quick delivery and varied quality (high, medium and low) PV water systems. It has the tendency to favour poor people who cannot afford the full upfront cost of the system.

One challenge with the FfS scheme is that, when the two parties (service provider and users) do not agree on a fair deal in fixing the fee that the users should pay, the scheme is not sustained. From the study, it has been revealed that during the RESPRO implementation, politicians kept the fee artificially low so as to allow more people to enjoy the rural PV electrification. Consequently, the service provider could not generate adequate revenue to afford transportation costs to visit beneficiary communities; the systems were thus left unattended without proper management, so the project failed (JICA, 2011). This has the tendency to undermine the confidence and trust of prospective adopters of the PV system.

Another model incorporated in the PV water system financing framework, similar to the fee-for-service is the Build Operate and Transfer model discussed in the next section.

7.5.2.3 Build Operate and Transfer

With this mode, a service provider invests in the system, installs and manages it. He then provides the service to the user institution or community for an agreed period of time (usually 10 years and above depending on the investment portfolio and expected profit) and later transfers ownership of the system to the beneficiary community or institution. A contract is set with well documented terms in the Memorandum of Understanding (MOU) between the service provider and the user community. Two examples found on the field are the BOT contract between an NGO and the Ziope community and between; Ho Polytechnic and a PV energy producing company whose Chief Executive is a respondent coded AGSi 7. In the case of Ziope, the NGO provides safe drinking water for the people in the town and this will last for a period of 15 years as reported in section 5.4 of chapter 5. For Ho Polytechnic, a 10 kVA grid-connected PV system is provided (in addition to diesel fueled generating plant) by AGSi 7 to supply power to the institution's Frequency Modulation (FM) station and students' central halls for a period of 12 years after which the technology will be transferred to Ho Polytechnic..

With regards to the new framework shown in figure 7.2, the BOT scheme is expected to apply to Piped Scheme (see section 5.2.2) grid connected PV water supply system with many distribution points which will be supplying water to a large community or township with population ranging between 2001 and 50,000 people. Typical examples of communities in the case study area that should take advantage of this BOT scheme to have grid connected PV water supply system is Kpetoe and Ziope; because the piped scheme already exists and their population also falls within the specified range. Currently Ziope practices the BOT scheme with power supply from the grid or diesel engine (during off grid period). The market characteristics for this scheme are high system cost, long delivery time, and standardized high quality product from prequalified companies.

Normally, grid connected PV systems provide the opportunity for making a lot of savings from power utilization. For instance, the new monthly tariff Ho Polytechnic pays to the PV service provider (AGSi 7) is lower than the tariff it used to pay to the grid company by GHC 250.00 (USD 80.00). When the system is transferred to the Polytechnic at the end of the contract period, the institution would no longer pay anything to the supplier; it may pay very little to the grid company or receive credit from it on Feed-in- Tariff scheme.

7.5.2.4 Solar Energy Utilisation Loan Scheme

The study has brought to the fore the need to have solar PV Utilization Loan (PVUL) which is similar to institutional car loan in most of the organizations in Ghana. Interests on these loans are usually very low within the repayment period but vary from one institution to the other. The PVUL scheme under the new framework is anticipated to be applicable to Piped Scheme with grid connected PV water supply system having limited distribution to supply water to communities of population within the range 1,201-2000 people. A typical example of a community that could take advantage of this PVUL scheme to have grid connected PV water supply system is Akpokorpe. This community over the years has effective water tariff collecting mechanism (pay-as-you-fetch); they could easily pay back such loan. The market characteristics for this scheme is also high system cost, long delivery time and a standardized high quality product from prequalified companies.

Farmers can take advantage of this loan scheme to have all year round irrigated farms as well as treated sachet and bottled water vendors.

7.5.2.5 Donation Mode

With the donation model, the PV system is transferred to the community as a gift. A typical example is the system installed at Kpota (chapter 6) for the current study. For this framework (figure 7.2), the donation scheme is for the installation of a stand-alone PV system mounted on point sources such as boreholes. The target group for ownership is farming communities as well as private and public institutions. The single panel (145-165 Watts) PV water system has been donated by the Ghana Cocoa Marketing Board (COCOBOD)

The market characteristics of this scheme are high system cost, long delivery time, and a standardized high quality system from prequalified company donors (NGO, churches etc.).

One major setback about this donation model is that; donors sometimes do not build capacity for local people from the benefiting communities by way of training them on the systems so that they can repair and maintain them. Most of such systems found on the field are dysfunctional. For example, an area mechanic stated that the problem with the COCOBOD system has always been the electric motor.

Table 7.2: Summary of Financing Modes for Each Case Study

Community	Financing Mode^a	Remarks
Kpetoe	BOT/FfS	Although the water management board prefers BOT financing mode, the FfS mode seems a better option in Kpetoe. A private investor can better operate and manage a grid connected PV system than the town's water board. Inhabitants will have more confidence and trust in the investor than in the water board and will patronise the system better.
Ziope And Akpokorpe	BOT/FfS	The water board in Ziope prefers BOT financing model because they claim the people are already used to the BOT adapted to the water supply system currently. The BOT and FfS (and even PV loan scheme) could apply to Akpokorpe since water tariff collection is already easy here. A grid connected PV water system operated on BOT seems a better option and is recommended for both communities.
Kporta	Donation	Donation as a financing mode for PV water system applies in Kporta with the current research installed PV; and it is recommended for the community. This mode does not necessarily require any form of paying back to the donor/investor apart from revenue generation for the PV maintenance. The community does not collect enough water from the system except during the dry season; any other financing mode would not favour the investor.
Mangoase	BOT	The chief of Mangoase prefers BOT financing model since they used to pay tariffs when their hand pump was functioning; in addition they would want to own the PV system in the future. FfS may not benefit the investor and so the system cannot be sustained. The researcher thus recommends BOT for Mangoase
Lume Avete	Donation/BOT	The people in Lume have experienced the value of the PV system and indicated their preparedness to use the donated PV. Although their current PV water system was a donation, the water management team and the people have demonstrated their readiness to own and adequately manage the system. A BOT financing mode also looks practicable and will be preferable to FfS.
Adaklu- Anfoe	Donation/BOT	A PV water system based on BOT financing model is most appropriate even though the people have been using a donated PV system. Currently there is lack of knowledge about the PV. The BOT will enable the community to understudy the investor for a long period (contract duration) before the PV is transferred to the community.

^a Four communities studied in the case study area prefer the BOT model

From the field study, it is clear that the high initial cost of the PV system necessitates governmental and philanthropic (development partners and NGOs) intervention for the rural communities to acquire the PV infrastructure as observed at Lume Avete, Kporta and the farming communities which benefitted from Ghana COCOBOD's PV systems. However, the sustainability of such systems can only be ensured when the beneficiary communities are willing to complement government or NGOs effort by paying realistic water tariffs that will enable operational cost recovery as Lume Avete people are currently doing (even though this particular tariff is too low in the estimation of the researcher). The opposite is the case at Adaklu Anfoe where the community fails to pay tariff and so resorts to using unimproved water from river Tordze. This practice is due to lack of knowledge about the technology but not a case of poverty; since the PV panels were shaded with leaves and their surroundings in untidiness at Adaklu Anfoe.

The above observation accords with the arguments put forward by Bhattacharyya et al. (2015) and Chmiel and Bhattacharyya (2015). They argue that enough grant fund has to be mobilised to create the electricity infrastructure in developing countries; and even considering developed nations, capital subsidy cannot be ignored for off-grid electrification. They also note that the poor in developing countries should not be expected to pay for their off-grid electricity supply systems.

Apart from 100 % cash payment model, the four other proposed models seen in figure 7.2 have a third party (NGO, government etc.) intervention; thus, there should always be a financial support (intervention) to enable rural communities own PV system.

The author believes that the adoption of the two frameworks presented in this chapter would facilitate the diffusion of the solar PV water pumping system in Ghana. Having discussed the results, the next chapter presents some conclusions to the study and recommendation.

CHAPTER EIGHT: CONCLUSION AND RECOMMENDATIONS

This chapter presents a summary of the major research findings and conclusions. Some key recommendations are made for stakeholders concerning the adoption of solar PV water pumping systems for sustainable water supply. Five communities within, and two outside the main study area (with PV systems already in use and needed to be studied) were considered and some practitioners in the solar PV industry also participated in the study. The researcher designed a solar PV pumping system for the borehole of Kporta community and the performance of the system was evaluated in relation to cost, its reliability and how the people collected water from it. The study addressed the factors that influence the take up of solar energy for water pumping in rural locations of the country. The major conclusion drawn are summarised below, in terms of the original objectives.

8.1 Progress Against Objectives

Objective 1: *To carry out case studies of water abstraction in a number of remote villages of Ghana*

This objective has been fully achieved. Observation, interviews and questionnaire were used to conduct the study to achieve the objective. A total of 7 villages (five within and two outside the study area) were identified and studied based on their specific water delivery experiences. The 7 cases have been summarised in table 5.10 and are referred to within the following section. Structured observation made on water facilities gave empirical evidence about the deplorable situation of water facilities in the district as stated above. The recommendations about the preferred model and the way forward for each community have been supported by the study.

Kpetoe

At Kpetoe, the main water supply is treated pipe borne water (abstracted from river Todze) in addition to rainwater which is harvested only in rainy season. Grid electricity is the only source of power but supply is erratic. Grid connected PV system based on build operate and transfer (BOT) is the preferred financial model to ensure stable supply of potable water. Poor management services decrease inhabitants' confidence in the water and sanitation management team and this adversely affects revenue generation.

Ziope

The main water supply in Ziope is treated pipe borne water (abstracted from a dam by an NGO) in addition to rainwater which is harvested only in rainy season. The people get regular supply of water from the NGO. Grid electricity is the main source of power but supply is sometimes unreliable so the NGO uses diesel powered generator. Grid connected PV system based on build operate and transfer (BOT) is the most preferred financial model as this is already being practised with the grid electricity. Cost of water is more expensive in Ziope than it is in Kpetoe since supply is from a private NGO.

Akpokorpe

Akpokorpe has only one source of water supply which is a mechanised borehole using the grid. The quality of water abstracted from the borehole is acceptable to the people. Supply does not absolutely meet demand and the situation gets worsen in the event of erratic power supply. The water supply situation is better here than in Ziope and Kpetoe in terms of cost however, expertise in solar PV is not available. Meanwhile, grid connected PV system is the preferred technology in the community based on BOT financial model.

Mangoase

The community has two dysfunctional boreholes and one dry pond. The people of Mangoase therefore trek long distances (more than 2km) to collect water for domestic use. No WATSAN committee was found in the community so the head chief assumed responsibility for development projects with some supports from his elders. No solar PV system was found in the community neither did the expertise exist for the technology. The Agotime-Ziope district assembly has to take pragmatic action to provide water to the people.

Kporta

Kporta is the main research community with the installed PV system. The village has one artificial dam (pond) and one borehole initially fitted with NIRA hand pump and poor water quality discouraged the people from maximum utilisation of the new PV system. The largest volume of water the people collected from the system (recorded with an installed water meter) in one month was 14 % of the PV system's designed capacity and 5.2 % for one year.

The underutilisation of the PV demonstrated system has adverse implications for the community and also for the adoption of the PV system. The people risk losing the system to another community where it can be used adequately. The recommended financing model is donation of the PV system in addition to water treatment equipment.

Lume Avete

The community has one 1.12 kW capacity PV system that supplies groundwater since 1999 and the water is visually clear, soft and pure. The management team is very active in this community; indeed, the best practice was observed here and it has propensity to encourage adoption of the system and scale up the diffusion of the technology in Ghana. The current price of 2 Ghana pesewas (GHC 0.02) at which water is sold in the village is however too low and needs to be reviewed upwards to meet the economic realities in the country while remaining affordable to the people. Even though the PV system in use was donated, BOT financing could equally be suitable in this community since the people demonstrated preference for the PV.

Adaklu Anfoe

Adaklu-Anfoe has one 1.68 kW capacity PV water system while the river Tordze which the people said is polluted with human excreta and animal dung also passes through the outskirts of the town. Because of a weak water and sanitation management team and lack of technical know-how about the PV, the system does not produce sufficient water. Thus, the people reverted to collecting water from the river which serves as the main source of water supply to the community. The practice tends to hinder the adoption of the PV system and hence its diffusion. Even though the community has been using a donated PV water system, a BOT financing model is most appropriate as this will enable the people to understudy the investor for a long period (contract duration) before the PV is transferred to the community.

Objective 2: *To identify the economic, cultural and technical factors that influence water abstraction in the rural locations of Ghana in general, and with the use of solar PV in particular.*

This objective has also been achieved with case-based action research conducted through interviews and participant observation.

In spite of low patronage, the PV system proximity to the people of Kportia saves them from spending so many hours in search of water. The pupils' education may improve as absenteeism from and lateness to school, due to the need to collect water decreases. The provision of safe water from the PV system also created access to hygienic water sources and no theft and insecurity (through vandalizing the PV system) were reported.

The cultural practices of pooling resources in Kportia can be adopted for the procurement of community PV water system when communities are properly sensitised and educated about the technology. Technically, the severe water hardness and unacceptable taste, lack of technical expertise for the PV and low awareness about the technology coupled with lack of coherent and coordinated policy are factors that influence the adoption of the system. Economically, high upfront system cost and lack of a viable industry have also been considered as key factors that influence the adoption of the PV system. Since rural people are low income earners acquisition of the PV system will be difficult unless there is an intervention through a build-operate-and-transfer (BOT) financing model or donation by the government or its development partners and NGOs.

Objective 3: *To design and evaluate a solar PV water system*

A PV water pumping system was designed, installed (with the full involvement of the Kportia community) and its performance evaluated. This objective has been achieved; the system provides plenty of water although the people underused it except in dry season.

Objective 4: *To develop market and financial frameworks for a solar PV water system for rural Ghana*

Interviews were conducted, observations made and literature reviewed; these provided the basis for the development of solar PV water system diffusion for Ghanaian market and solar PV water system financing frameworks presented in figures 7.1 and 7.2 respectively.

8.2 Conclusion

The study has explored the viability of solar energy for PV water pumping in rural locations of Ghana using the Agotime-Ziope district of the Volta region as a case study. The following specific conclusions have been drawn:

1. Source of Water and Supply Challenges

Groundwater is the main source of water supply in the Agotime-Ziope district and it is accessed through borehole fitted with hand pumps; surface water sources (rivers and streams) are also accessed for domestic use. The potable water provision from local treatment plants and groundwater sources found within the Agotime-Ziope district is inadequate. During the dry season, surface water levels reduce and some dry up completely making water and sanitation issues major development concerns for most communities in the district. The most common method of revenue generation of water collected from improved sources, is “pay-as-you-fetch” when effective water management system is put in place (e. g. Lume Avete and Ziope). But water from unimproved sources (from dams, streams and rivers) are collected free of charge and this discourages adequate use of improved sources. An important finding revealed by the study is that poor water quality (high salinity and hardness) impacts negatively on the PV water system usage. Therefore any discussion on groundwater supply must not be limited to extraction only but must focus on water treatment.

2. Water Facilities and Their Conditions in the District

Many water facilities (hand pumps mounted on boreholes) were found not to be functional as seen in Appendix VI, consequently they have been abandoned. Poor management of the water systems by water and sanitation management teams (WSMTs) due to lack of funds, inadequate remuneration coupled with lack of motivation for the WSMTs are some of the causes. Most of the teams are either dormant or non-existent. The ultimate cause of the poor facility management is a lack of supervision and supports (logistical and technical) from the district assembly to beneficiary communities. For those communities where the facilities are functioning, people’s unwillingness to pay water tariffs, and in some cases the intermittent supply of water to the people cause low patronage. Water facilities and supply are thus unsustainable.

3. Power Supply Situation

Power supply in most parts of the district is basically from the grid. However, supply in connected communities has not been reliable or regular which further worsens the poor water supply situation in the district most especially at Kpetoe. No solar PV system was found in the district except in Hododokorpe (listed in Appendix VI) where a single panel PV system was installed.

4. Potential and Challenges for Solar PV Usage

Great potential exists for solar energy utilization for PV water pumping in rural locations of Ghana but high initial capital cost of the system, lack of awareness about the technology and lack of viable industry for the system adversely influence the adoption of the technology.

5. PV Market Segments

In addition to the four market segments of the existing structure are two new segments (financial institutions and donors). Thus the proposed solar PV water pumping system diffusion framework for the Ghanaian market shown in (fig. 7.1) has six segments.

6. Financial Model Options

Although the successful implementation of the two frameworks (depicted in figures 7.1 and 7.2) will, to a large extent, depend on a high level of political supports and development of the enabling environment, the build-operate-and-transfer (BOT) financial option favours almost all the communities to procure the PV water system, either as a stand-alone (for off-grid areas) or grid connected technology (for grid connected areas).

Clearly solar photovoltaic is a viable source of power for rural water supply in Ghana. However, because of the high initial cost of the system and the fact that people in such rural locations are usually low income earners, they should not be expected to pay for their off-grid electricity supply systems. The provision of capital subsidy is imperative and hence enough grant fund must be mobilised by the government, NGOs and development partners to create the PV infrastructure while the beneficiary communities must also be willing to pay realistic water tariffs to enable operational cost recovery.

The next section provides relevant recommendations.

8.3 Recommendations

The following recommendations have been made to increase and facilitate the adoption of PV for water pumping:

1. That the use of the new frameworks developed in this thesis should be encouraged by stakeholders and policy makers. Hence broad stakeholder engagement across diverse sectors is necessary.

2. The build-operate-and-transfer (BOT) financing model should be adopted by rural communities for procurement of PV water systems since this model has the most advantage; it is affordable and helps the benefiting community to understudy the investor for a long period before the system is transferred to the community.
3. Government policies and programmes on energy that takes renewable energy (particularly solar PV) technologies into consideration must be coherent and properly coordinated in order to create a favourable and enabling environment for easy implementation of such policies to promote adoption of the PV water system.
4. Training institutions should organise and run training courses for PV consumers and providers at all levels including the training of community and PV agents.
5. Finally, future research should develop methods to remove salt and dissolved minerals such as iron, manganese and fluoride from groundwater and develop a better understanding of how best to supply safe/palatable water in rural areas. This could use stand-alone PV or grid connected PV systems to run water purifying equipment to reduce cost.

8.4 Contribution to Knowledge

There has been much research in the area of rural water supply (Limantol, 2009; Gbedemah, 2010; Adow, 2013) and also in solar PV for rural electrification (Dadzie, 2008; Atsu et al, 2016). A few PV water systems have also been installed in villages within Ghana. However, no scholarly study was found in the literature on rural water supply using a PV water system in Ghana similar to the one in the current research.

The researcher used multiple approaches (qualitative, quantitative and mixed methods) in the research and had actually installed a solar PV water system into one village which is a new development introduced into the district. The study reveals that a PV water system installed in a community will not be put to optimum use when alternative water sources with acceptable water quality (though unhygienic) compete with the technology. Groundwater supply must therefore consider water treatment as well as extraction - as demonstrated at Kpota.

New market structure has been developed to facilitate diffusion and adoption of PV. Two Financial Models (PV Loan scheme and BOT) have been added to existing models in the new PV financial framework.

The significance of the study is that the thesis would be useful to researchers, the solar PV water system manufacturers, academics, PV system designers and installers, decision makers and potential market groups (real estate industry and public educational institutions).

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- Zhao, Z. (2012). *High efficiency single-stage grid-tied pv inverter for renewable energy system*. PhD Dissertation in Electrical Engineering Virginia Polytechnic Institute and State University

List of Publications by the Author

1. Dzokoto, S.T.K. (2016). *Exploring the viability of solar photovoltaic for water pumping in the rural locations of Ghana: A case study of Agotime-Ziope district of the Volta region*. Presented at PhD Seminar Series in the Ho Technical University on 15th December, 2016.
2. Dzokoto, S.T.K; Wright, A.; Lemon, M.; Akple, M.S and Agodzo, S.K. (Undated). *Challenges of solar photovoltaic water pumping system adoption in rural communities of Ghana*. A paper yet to be published

APPENDIX I

Consent Form



**Topic: Exploring the Viability of Solar Photovoltaic for Rural Water Supply in Ghana:
A Case Study of Agotime-Ziope District of the Volta Region**

Name of Researcher: Seth T.K. Dzokoto, PhD Student; Institute of Energy and Sustainable Development- De Montfort University Leicester, UK

Please initial box

1. I confirm that I have read and understand the information sheet for the above study and have had the opportunity to ask questions.

2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving reason.

3. I agree to take part in the study

Please tick box

Yes No

4. I agree to the interview being audio-recorded

<input type="checkbox"/>	<input type="checkbox"/>
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5. I agree to the use of anonymised quotes in publications

<input type="checkbox"/>	<input type="checkbox"/>
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Name of Participant:

Date:

Signature:

Seth T. K. Dzokoto (Researcher)

Date:

Signature:

APPENDIX II

Interview Guide (Senior Personnel of Agotime-Ziope District Assembly)

This interview guide was designed to elicit relevant data from senior personnel of Community Water and Sanitation Agency at the Volta regional office and the senior personnel at the Agotime-Ziope District Assembly. Although the questions cover same thematic areas, specific questions were asked based on the mandate of each officer. Typical questions for the district engineer (Chairman of DWST) are provided below

BACKGROUND INFORMATION

Q: Which year was the District Water and Sanitation Team (DWST) was established?

Q: What is the composition of the DWST?

Q: How many communities are provided with water supply systems?

Q: How many of such systems are still functioning till today?

Q: Briefly out line policy guidelines of rural water supply in your district

Q: What role do you play in rural water supply in the District?

INCEPTION OF THE SYSTEM/COMMUNITY INVOLVEMENT

Q: What role does the DWST play in promoting community participation in rural water supply projects?

Q: How do you inform communities prior to provision of the water facilities?

Q: What inputs are required from the community at the Planning stage?

Q: What inputs do you require from the community at the construction stage?

Q: What inputs do you require from the community at the Post construction stage?

Q: How are women involved in the water supply project?

Q: Do you think the current level of community participation is adequate?

Q: Make suggestions for improved performance

Q: How did the beneficiary communities contribute financially to the project?

Q: How would you assess the involvement of rural communities in the discharge of your duties?

Q: In your opinion what factors hinder effective community participation in rural water projects in the District?

Q: What factors influence the choice of technology (Pipe scheme)?

POST CONSTRUCTION SUPPORT

Q: What kind of support do you normally give to beneficiary communities after construction?

Q: How often do you visit beneficiary communities to offer post construction support?

Q: Do you provide training to communities in the management of their water facilities?

Q: How often are these trainings carried out?

Q: How do communities fund operation, maintenance and repair costs?

Q: In your opinion, would you say that rural communities are capable of managing their water facilities?

Q: If yes give reasons, if no, give reasons

Q: In your opinion are these post construction supports to communities enough and satisfactory?

Q: If Yes Why, If No Why.

Q: What are major constraints in the provision of post construction support water to rural communities?

INDICATORS OF FACILITY SUSTAINABILITY

Q: In your view are communities managing their water facilities in a sustainable way?

Q: If Yes, give reason, if No give reasons

Q: Which management system would you recommend for the rural water delivery?

POWER USE IN COMMUNITY WATER SUPPLY

Q: What is the source of power for supply of your water in your district?

Q: How regular is the power supply to the water facility?

Q: Do you have solar photovoltaic powered water supply system in your community?

Q: Would you like to use solar power for the district water supply needs?

Q: Can you give reasons for your answer given in above?

Q: What recommendations would you make towards the sustainability of community rural water systems in your district?

APPENDIX III

Questionnaire on Exploring the Viability of Solar Photovoltaic for Rural Water Supply in Ghana: A Case Study of Agotime-Ziope District of the Volta Region



Institute of Energy and Sustainable Development (IESD)

This questionnaire has been designed to elicit relevant information on the use of solar energy to pump water for rural dwellers in Ghana. The research is purely for academic purposes and any information received will be treated with utmost confidentiality.

Questionnaire for Community Senior High Students

Please tick (✓) the option that fits your views; where appropriate write down your view.

A) DEMOGRAPHIC INFORMATION

1. Community:
2. Name of Respondent (Optional):
3. Gender: Male [] Female []
4. Age: i) 16-19 yrs. [] ii) 20 -26 yrs. [] iii) 27 years and above []
5. Level of education: i) Middle School/JHS [] iii) SHS [] iv) Tertiary []
6. Marital Status: i) Married [] ii) Single [] iii) Divorced [] iv) Widow/(er) []

B) SOCIO-ECONOMIC INFORMATION

7. What is the major occupation for people in your community? i) Farming [] ii) Kente weaving [] iii) Teaching [] iv) Fishing [] v) Trading []
8. What is the level of your monthly expenditure (GH¢)?: (i) Below GHC90.00 [] (ii) Between GHC 90.00 and 120.00 [] (iii) Above GHC 120.00 []
9. State the main source of water supply for drinking in your community. Please you may choose more than one. (i) Dam [] ii) Borehole [] iii) Hand-dug well [] iv) Stream / River [] v) Piped [] vi) others, please specify
10. Is the source stated in Q10 wholesome for drinking? Yes [] No []. If yes go to Q13
11. If No, how do you treat it? (i) Adding alum/moringa [] (ii) Boiling [] (iii) Filtration [] (iv) Exposure to sunlight [] (v) Others, specify:
12. Is the source of water adequate in terms of quantity? Yes [] No []

13. Do you pay for the water you use? Yes [] No []. If No, then go to Q18
14. How do you pay (tariff) for the water? (i) Pay- as- you-fetch []
(ii) Fixed monthly levy [] (iii) Purchase []
15. How much is the water sold per 18 litre bucket (i. e. big bucket)?
i) Maintenance/Repairs [] ii) Personal gains [] iii) Community development [] iv) Bills payment [] v) Treatment of water [] vi) No idea []
16. What does your community use the water tariff (i.e. the money collected) for? i) Maintenance/Repairs ii) Personal gains iii) Community development iv) Bills payment v) Treatment of water
17. Do you get enough water supplies all year round including dry season? Yes [] No []
18. What do people in your household use water for? (i) Domestic (i.e. cooking and washing) [], (ii) livestock [] (iii) irrigation []
19. Which categories of people usually go out to fetch water for domestic use?
(Please you may choose more than one)
(i) Female youth [] (ii) Male youth [] (iii) Women [] (iv) Men []
20. How much quantity of water do you use per day? 1-2 buckets [] 3 or more buckets []

C. TYPE OF WATER SUPPLY FACILITY/SYSTEM

21. What type of water facility do you have in your locality? (i) Mechanized Piped System [] (ii) Gravity-fed Water System [] (iii) Ghana Water Company Limited Connection [] (iv) Any other (specify):
22. Do you get enough water supplies all year round with this facility? Yes [] No []
23. In your opinion, who maintains the facility? i) Community / Opinion leaders [] ii) Assembly Man [] iii) Member of Parliament (MP) [] iv) Nobody []

D. SOURCE OF POWER SUPPLY

24. Do you know the source of power for your water supply? Yes [] No []
25. If yes, what is the source of power for your water supply? (i) Generator []
(ii) National Electricity [] (iii) Others, please specify
26. How regular is the power supply to the water facility? (i) Daily [] ii) Weekly []
(iii) Daily but intermittently

27. Would you like to use solar power for your water supply needs? Yes [] No []

Don't know [].

28. Can you give reasons for your answer given in Q27?

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Thank you very much for your time and participation

APPENDIX IV

Participant Information Sheet

Dear Participant,

I would like to ask you to participate in the data collection for a study on **Exploring the Viability of Solar Photovoltaic for Rural Water Supply in Ghana: A Case Study of Agotime-Ziope District of the Volta Region**

Solar Photovoltaic Water Pumping in Rural Communities in Ghana: A Case Study of Agotime-Ziope in which your settlement/organisation has been adopted as one of the locations for case studies. This study is being carried out as part of a PhD in Renewable Energy in De Montfort University, Leicester- United Kingdom.

Kindly note that while personal data are not required, nonetheless all data collected will be anonymised. However, the name of your settlements/organisation might be disclosed for the sole purpose of originality of study. The main thrust of the study is to garner information that cover but not limited to the following issues:

- The type of energy source(s) being presently utilised by rural dwellers for their water supply needs.
- The orientation and perception of people in the use of solar energy
- The barriers militating against the take-off of solar energy in rural water delivery
- The source of water used by the community
- The acquisition, operation and maintenance of rural water supply facility
- The sustainability of regular supply of wholesome water in the rural communities
- The policies Government/Individuals can adopt to enhance the implementation and utilisation of renewable energy resources.

While participation in this study is entirely voluntary, your co-operation is being sought as this will enhance a robust study that could lead to the overall improvement of the life of the rural dwellers in Ghana. It will involve face - to - face interview and questionnaire that will not last beyond 20 minutes.

You may decide not to answer any of the interview questions if you wish and you may also decide to withdraw from this study at any time by intimating the researcher.

We may ask for clarification of issues raised in the interview sometime after it has taken place, but you will not be obliged in any way to clarify or participate further.

The information you provide is confidential and will be treated only as a source of background information alongside literature-based research and interviews with others. The information will not be used for any other purpose and will not be recorded in excess of what is required for the research.

Your name or any other personal identifying information will not appear in any publications resulting from this study. Even though the study findings may be published in international conferences and journals, there are no known or anticipated risks to you as a participant in this study.

If you have any questions regarding this study or would like additional information please ask the researcher before, during, or after the interview.

Yours Sincerely,

Seth T. K. Dzokoto

PhD Student

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0244511010; 0508007537

APPENDIX V

Interview Guide for Association of Ghana Solar Industries



Institute of Energy and Sustainable Development (IESD)

QUESTIONNAIRE ON SOLAR PHOTOVOLTAIC POWERED WATER PUMPING IN THE RURAL (REMOTE) LOCATIONS OF GHANA: A CASE STUDY OF AGOTIME-ZIOPE DISTRICT, GHANA

This questionnaire has been designed to explore relevant information that will help address the barriers to the take up (adoption) of solar energy for water pumping in off grid locations in Ghana. The research is purely for academic purposes and any information received will be treated with utmost confidentiality. **Please provide the necessary answers to the following questions.**

1. What is the name of your company/establishment?
2. What does your company/establishment do?
3. Do you have any demonstration centres where your products, with their capacities, are being used in Ghana? Please state them.
4. Do you face any market challenge in transacting business as an establishment? Yes/
No
5. Further to question 4, can you explain how solar energy use could be increased and improved in Ghana?
6. Do you know any policies put in place to promote renewable energy application in Ghana? Please state
7. Are there any incentives for dealers in renewable energy equipment and programmes?
8. Which of the following technologies will you prefer to use for remote area (off-grid locations) water supply; solar photovoltaic and wind power? Please give reason
9. How do you foresee rural dwellers responding (favourably or unfavourably) to the use of solar photovoltaic water pumping system for their water supply needs? Give your reasons
10. Do you have any renewable energy business or trade association in Ghana to promote your business? Please state

11. Do you have any comment to make on how best renewable energy, solar in particular, can be promoted in Ghana?

APPENDIX VI

Results Obtained from Structured Observation

Appendix VI shows results obtained from structured observation made on water facilities in 35 (out of about 100) randomly selected communities in the Agotime-Ziope district. It indicates the sources of water, type and conditions of the facilities.

Sampled Communities without Mechanised Water System

S/N	COMMUNITIES	SOURCE OF WATER	WATER FACILITY	CONDITION
1	Wodome (Togo side)*	BH/STR	2 Hand pumps	None Functional
2	Wodome (Ghana side)*	BH/STR	1 Hand pump	Functional
3	Sarakope	Dam/BH/STR	1 Hand pump	Not Functional
4	Adevokope	Dam/STR	No Facility	Rely on Sarakope source(3)
5	Vodzakpo	Dam/STR	No Facility	Rely on Sarakope source (3)
6	Hiakakope	Dam/STR	No Facility	Rely on Sarakope source (3)
7	Sapalikope	Dam/STR	No Facility	Rely on Sarakope source (3)
8	Batume Junction	BH	4 Hand pumps	2 Functional (1 salty water)
9	Hododokope	BH/Well/PV	1pv/1Handpump	PV non functional
10	Agbokope	2 BH/Dam	Hand pump/1pv	None functional, rely on Ho
11	Kpekuita	River	No facility	Use river in dry season
12	Efiakpe	HDW	No facility	Use river in dry season
13	Hiagbakope	BH/STR/river	1 Hand pump	Use stream and river
14	Adedome	1 BH/STR	1 Hand pump	Not functional
15	Amegakope	BH/STR/river	1 Hand pump	Not functional, use river
16	Agorhokpo	River/STR	1 Hand pump	Not functional, use river
17	Azametikope	River	No facility	Use river
18	Akpaligakope	River	No facility	Use river
19	Kpelikope	River	No facility	Use river

20	Wortsikpo	Dam/piped	1 Tap	Functional
21	Anatikope	Spring/ 1 BH	Hand pump	Functional with hard water
22	Bedzokope	Dam/SPR	No facility	Use dam and spring
23	Oblema	BH/SPR	1 Hand pump	Not functional
24	Agohome	BH/SPR	1 Hand pump	Water is hard
25	Kwakutsekope	Rain water	No facility	Suffer in dry season
26	Mangoase	BH/Dam	2 Hand pump	None is functional, dry dam
27	Aforkpi	BH/Dam	1 Hand pump	Use dam, BH water is hard
28	Dohia	BH	2 Hand pumps	(NF) Use water from Dzalele
29	Logovi	Dam	No facility	Collect water from Kpota
30	Kpatsiklo	BH	1 Hand pump	Not functional (NF)
31	Tsrulume	BH	1 Hand pump	Functional
32	Wekor	BH	1 Hand pumps	Functional
33	Adzonkor I	BH/Dam	1 Hand pump	Functional
34	Adzonkor	Dam	No hand pump	Use dam water
35	Wudzedeke	Dam/BH/Rain /river	2 Hand pump	Abandoned

Source: Field Data, 2013/2014

*BH = borehole; HDW = Hand dug well Rain = Rain harvested water, SPR = Water from springs

Mode of Selection of the Communities

The researcher divided the district into three zones; upper (Agotime/Kpetoe), lower (Ziope) and middle (in-between Kpetoe and Ziope). The communities were then randomly selected for structured observation.

Number of available boreholes with hand pumps = 25

Number of hand pumps which were functional = 10 (40 %)

Number of dysfunctional hand pumps = 15 (60 %)

Number of communities with dams = 14 (56 %)

Number of communities with river/stream 21 (84 %)

APPENDIX VII

Manual Design of the Solar PV Water Pumping System

In sizing and designing PV water supply system, the basic requirements needed to be met are: the daily water demand of the community, the flow rate or the discharge, total dynamic head TDH (i.e. the height to which water should be pumped taking into consideration head losses) and meteorological data of the site (peak sunlight hour-PSH, solar insolation and hence design month). These have been discussed in section 2.7 of the literature and determined in the following section. The design set-up of the solar PV water system at Kporta has been presented after the design calculations.

Daily Water Requirement

The Community Water and Sanitation Agency (CWSA) provided a per capita water consumption for design purposes to be 20 litres. That is 20 l/day per person. Hence water demand for 250 people, $Q = 20 \times 250 = 5000 \text{ litres/day or } 5 \text{ m}^3$.

Daily Discharge

An estimate of the required flow rate of the pump is determined by the following equation Pelt (2012):

$$\text{Flow rate } q = \text{water demand in litre per } \frac{\text{day}}{\text{PSH}} \times \frac{\text{hr}}{60}$$

Using minimum PSH = 4.2 kWh/1 kW = 4.2 hr. Therefore the daily flow rate is:

$$q = \frac{\text{daily demand}}{\text{PSH}} \times \frac{\text{hr}}{60}$$
$$q = \frac{5000}{4.2} \times \frac{\text{hr}}{60} = 19.84 \text{ l/min}$$

The Grundfos WinCAPS predicted values are $0.9 \text{ m}^3/\text{h} - 1.13 \text{ m}^3/\text{h}$ (i. e. 15 l/min – 19 l/min)

Manual measuring performed (reported in section 6.10) is 20.83 – 24 l/min or averaged 22.42 l/min

Total Dynamic Head

This was made up of the sum of borehole depth from static water table to the top of borehole and elevation difference from the top of the well to the top of storage tank) x 1.1 (Pelt, et al, 2012).

Hence Total dynamic head TDH = $(43 + 2 + 5) \times 1.1 = 55 \text{ m}$

Determination of Design Month

From table 6.6, the minimum average monthly insolation value for Ho (the closest synoptic weather station to Kport) is 4.2 kWh/m²/day and this matches with the value for the month of July-August (table 6.6). Hence the design month based on minimum value is August.

Sizing Solar PV

In sizing the solar PV, the hydraulic and solar powers should be determined using the generally accepted methods. One of which has been suggested by Abu-Aligah (2011).

Hydraulic energy required in kWh/day

$$P_h = \frac{\rho g Q H}{3600000} \quad (\text{Abu-Aligah, 2011})$$

Where $\rho = 1000 \text{ kg/m}^3$ is the density of water, $g = 9.81 \text{ m/s}^2$ being acceleration due to gravity, Q is daily volume of water required in (m³/day), H is total dynamic head in (m).

$$P_h = \frac{1000 \times 9.81 \times 5 \times 55}{3600000}$$

$$P_h = 0.7494 \text{ or } 749.4 \text{ kWh}$$

The solar array power required (kWp)

$$E = \frac{\text{Hydraulic energy required (kWh/day)}}{(\text{Min daily solar irradiation} \times F \times \eta_{\text{sys}})} \quad (\text{Abu-Aligah, 2011})$$

Where F = array mismatch factor = 0.80 on average (a safety factor for real panel performance in hot sun and after 10-20 years) and η_{sys} = daily subsystem efficiency = 0.25-0.40 typically (Practical Action, 2010)

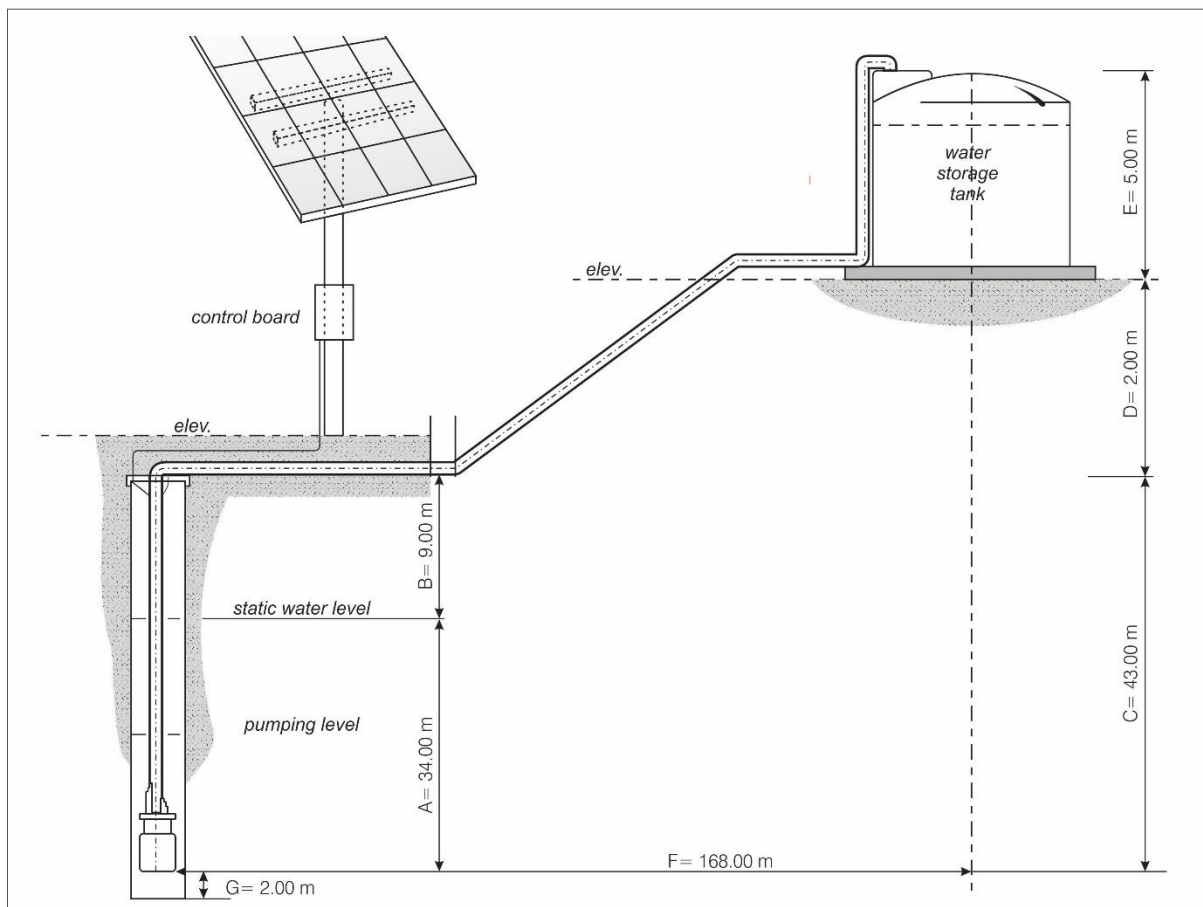
$$E = \frac{0.7494}{(4.2 \times 0.8 \times 0.40)}$$

$$E = 0.55759 \text{ kW/day or } 558 \text{ W/day}$$

NB: If the 5.1 kWh/m² per day is used in the manual calculation as in the software, then $E = 459.2 \text{ W/day}$ and hence six (6) of the panel (being 480 W).

In considering the manual method, the following parameters were used based on recommendations cited beside each assumed parameter: system efficiency $\eta = 0.4$ or 40 %; loss factor of 25 % due to the temperature and dust. The PV generator power is 558 W and would have required about seven 80 W_p panels as shown in the table below.

Month of sizing	Radiance (kWh/m ²)	Sunlight Hour (H)	Loss (%)	P_H (kWh)	E_{PV} W _c	Voltage (V)	Current (A)	Panels Configuration
August	4.2	4.2	25	0.7494	558	17.9	4.49	7 x 1



APPENDIX VIII

Financial Analysis of the PV Water System

The table below shows the financial analysis of the solar PV water system used in the current research. While the cost in respect of the PV system is the actual, that of the borehole is an estimate based on the field study. This is because no new borehole was constructed for the study except the old one at Kporta onto which the PV system was installed

Financial Analysis for the PV water system used in the research

Serial No.	Particulars/Items	Quantity	Unit Cost GHC	Total Cost GHC	Total Cost GBP (£)
1.	SQFlex 1.2-3 PV Pump	1	6974.5	6,974.50	1,341.25
2.	Solar panel GF 80	6	693	4,158.00	799.62
3.	Control Unit CU 200	1	1925	1,925.00	370.19
4.	Wire kit complete	1	875	875.00	168.27
5.	Shipping –Germany/Ghana	1	3325	3325.00	639.42
6.	Clearing/Duty cost	1	5419.05	5,419.00	1042.12
	Sub Total (a)			22,650.00	4,355.77
7.	PE pipe – 40 mm- 130 m	1	2350	2,350.00	451.92
8.	PE pipe fittings	7	85	595.00	114.42
9.	Raisin kit	1	75	75.00	14.42
10.	Cable clips	1	65	65.00	12.50
11.	Submersible cable 65 m	22	65	1,430	275.00
12.	Angle aluminium iron	5	110	550.00	105.77
13.	Bolts and nuts	50	0.95	48.00	9.23
14.	U-shape hocks	15	10	150.00	28.85
15.	Labour	3	833	2,500.00	480.77
16.	Sub Total (b)			7738	1,488.08
17.	Welded PV support structure	1	800	800.00	153.85
18.	Water storage tanks (5 and 10 m ³)	2	2,500	5,000.00	961.54
19.	Concrete	1	3,000	3,000.00	576.92
	Sub Total (c)			8,800.00	1692.30
	Grand Total (a+b+c)			39,188.00	7,536.15

Exchange Rate £1.00 = GHC 5.20

APPENDIX IX

Interview Guide Designed for Rural Communities where Water Supply Facility is Mechanised with Solar Photovoltaic (Lume Avete and Adaklu Anfoe)



Institute of Energy and Sustainable Development (IESD)

A. ABOUT YOU AND WATER USE IN YOUR HOUSEHOLD

1. Please give me a brief background about yourself
 - i. Your town:
 - ii. Age bracket:
 - iii. Sex: Male Female
2. How many people are there in your household including you?
3. How many sources do you get water from?
4. For each of the sources mentioned in q3 state what the water is used for
5. How much water do you use in your household per day (in terms of 18 litre bucket)?
6. How much water did your household use before the solar power water system was installed (in terms of 18 litre bucket)?
7. How much do you pay for the water? for 18 litre bucket?(a) using the new system (solar PV) (b) before new facility was installed that was
8. Who usually collects the water?
9. Has this changed before and after the new system was installed? If so or yes, why?

B. INCEPTION OF THE SYSTEM

10. Can you tell me the background to the arrival of the pumping system?
11. How did you get the solar pumping system into your community?

C. OPERATION AND MAINTENANCE OF THE SOLAR WATER SYSTEM

12. How is the system managed and who is responsible for overseeing the process?

13. Who is responsible for maintaining the solar pumping system?

14. Have there been problems with maintenance; if so what?

D. USE OF POWER TO PUMP WATER

15. What do you feel are the strengths of the pumping system?

16. What are the weaknesses of the pumping system?

17. How do you think the weaknesses you have identified could be addressed?

18. Has the solar water pumping system brought any change in your behaviour in relation to the use of water? Give details:

19. Do you think there are better sources of energy for pumping water?

If yes, what are these and why might they be better?

GENERAL COMMENT

Do you have any other comments about the solar water pumping system?